EW-3-82

June 1982

GAS TURBINE COMPARISONS USING THE EXERGY METHODS

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER EW-3-82	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) GAS TURBINE COMPARISONS USING THE EXERGY METHOD		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Professor Vincent J. Lopardo Mechanical Engineering Department		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS United States Naval Academy Annapolis, Maryland 21402		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE June 1982
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE UNCLASSIFIED

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Exergy, Gas Turbines, Second Law, Available Energy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Using the exergetic methods of the Second Law of Thermodynamics several gas turbine configurations are compared and evaluated. In all cases the primary loss of exergy is associated with the combustion process and the exhaust stream. The use of a regenerator reduces the overall exergy dissipation.

ACKNOWLEDGMENTS

The work for this paper has been supported by the Naval Ship Research and Development Center, Annapolis Branch under the supervision of Mr. Rolf Muench. His assistance is gratefully acknowledged.

Additionally, the author wishes to express his gratitude to Ms. Inez Johnson who diciphered many pages of calculations and prepared the manuscript.

ABSTRACT

Using the exergetic methods of the Second Law of Thermodynamics several gas turbine configurations are compared and evaluated. In all cases the primary loss of exergy is associated with the combustion process and the exhaust stream. The use of a regenerator reduces the overall exergy dissipation.

TABLE OF CONTENTS

The objective of this study was to evaluate and compare the exergy flows for four different gas turbine configurations.

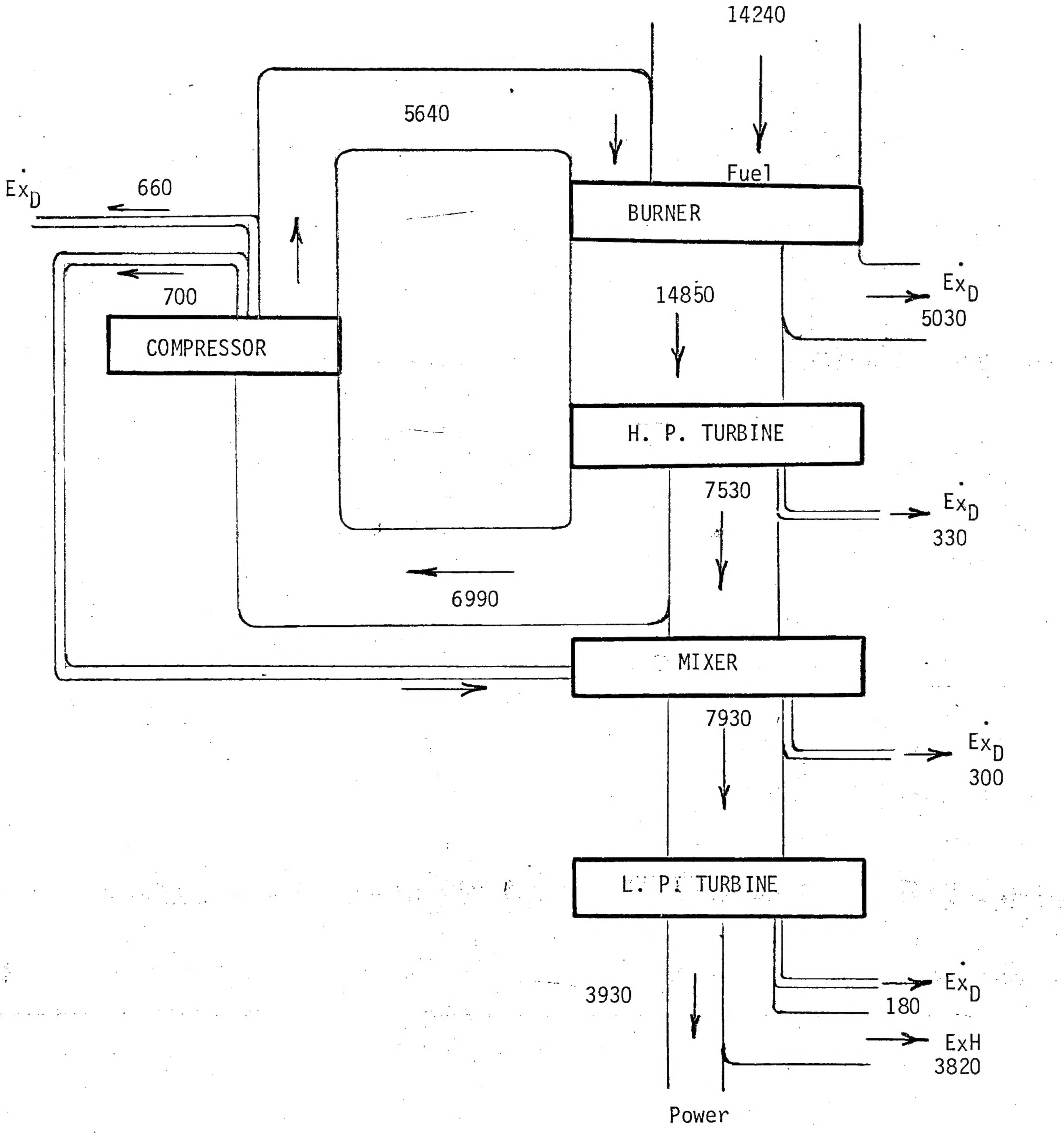
Method

The gas turbines investigated were: GTF990, GTF990 WR_{86}, GTF40WR_{86} and GTF40WR_{96}. The letters WR refer to "with regenerator" and the subscript is the regenerator effectiveness in percent. There were two approaches used in this study. The first was to assume that the fuel was $C_{10}H_{22}$ and to compute the enthalpies and entropies at each station using the JANAF tables. This method yields information of the actual exergy flow at each station and was used for GTF990 and GTF990WR_{86}. It is a more rigorous or detailed approach with all exergy values referenced to the same datum. The second method used the calculator program (see Report EW-9-81) for obtaining the properties in combination with the given lower heating value of the fuel. This method was used to determine the actual exergy losses or dissipation for all four turbines since the only known data were the LHV and the fuel air ratios. For a detailed description of the method see Report EW-2-82.

In both approaches the exergy was evaluated as $[(h - T_0S) - (h_0 - T_0S_0)]$ with the exergy of kinetic and potential effects neglected.

Results

Figures 1 thru 5 summarize the results of this study. Figures 1 and 2 show the exergy flows in turbines GTF990 and GTF990WR_{86} using dodecane ($C_{10}H_{22}$) as the fuel. Figure 3 compares the exergy dissipation for turbines GTF990WR_{86} and GTF40WR_{86}. Figures 4 and 5 give the losses for turbines GTF40WR_{96} and GTF990 respectively.



EXERGY FLOW GTF990
(All Units BTU/S)

Fig. 1.

EXERGY FLOW DIAGRAM
(All values in Btu/s)

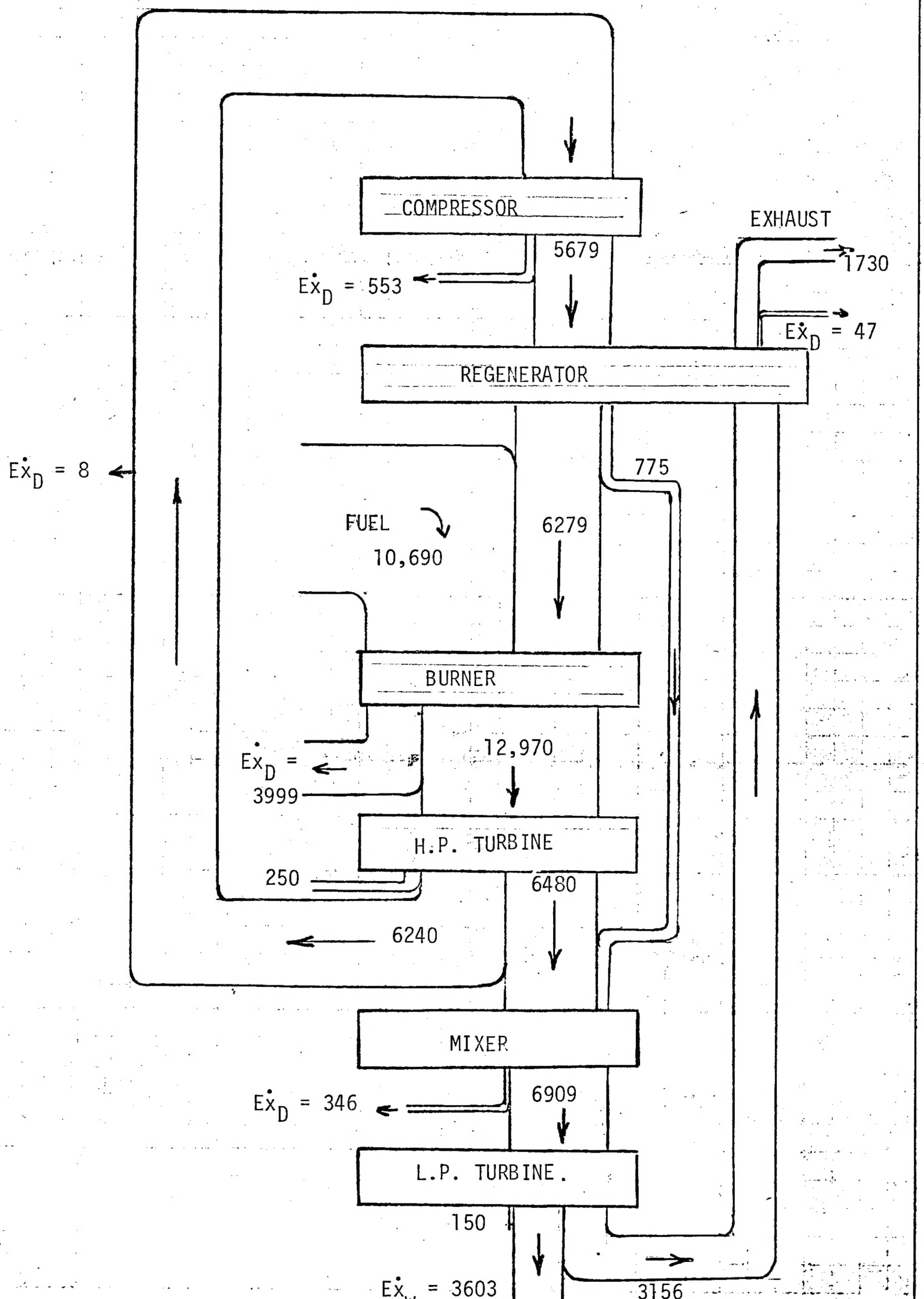
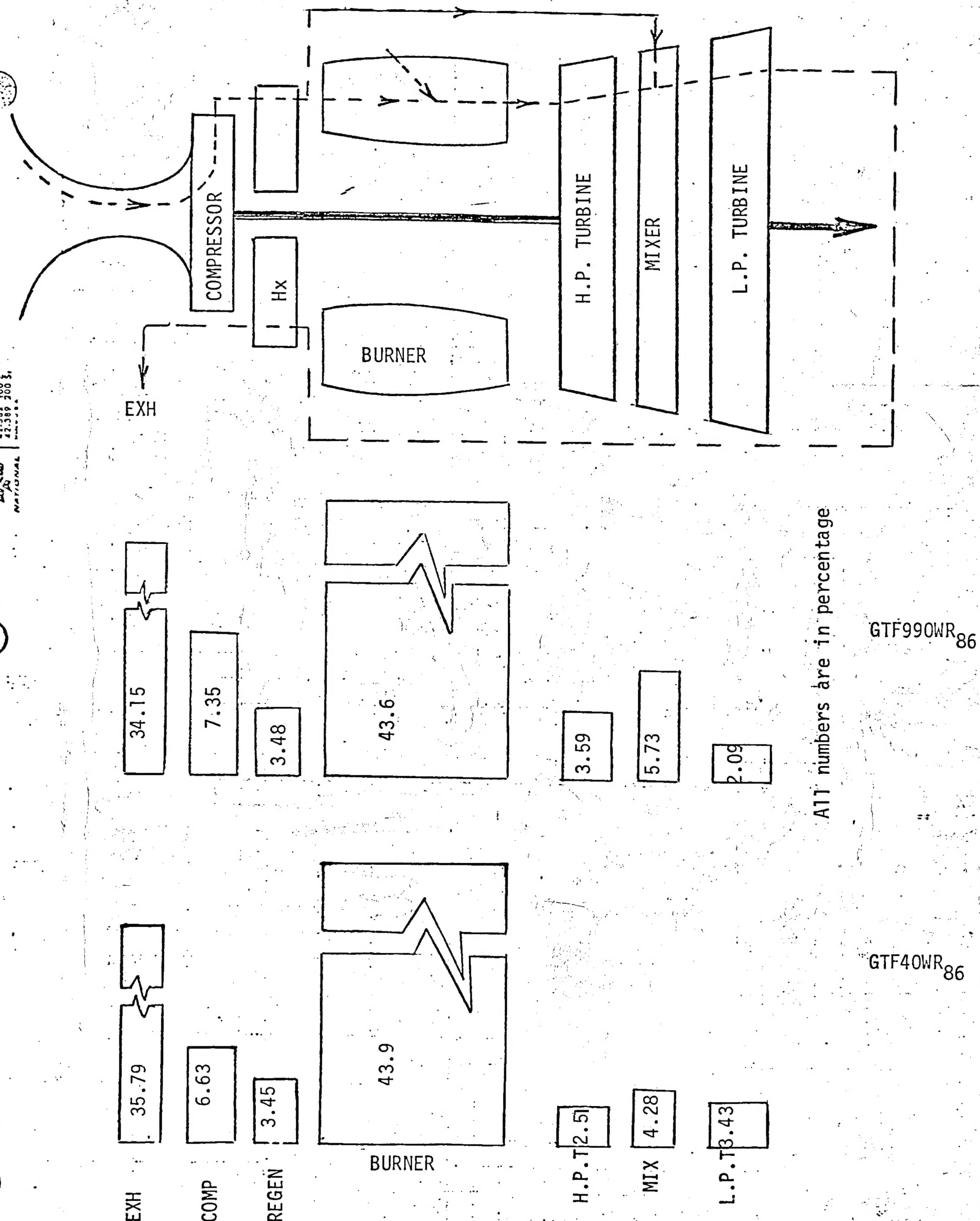
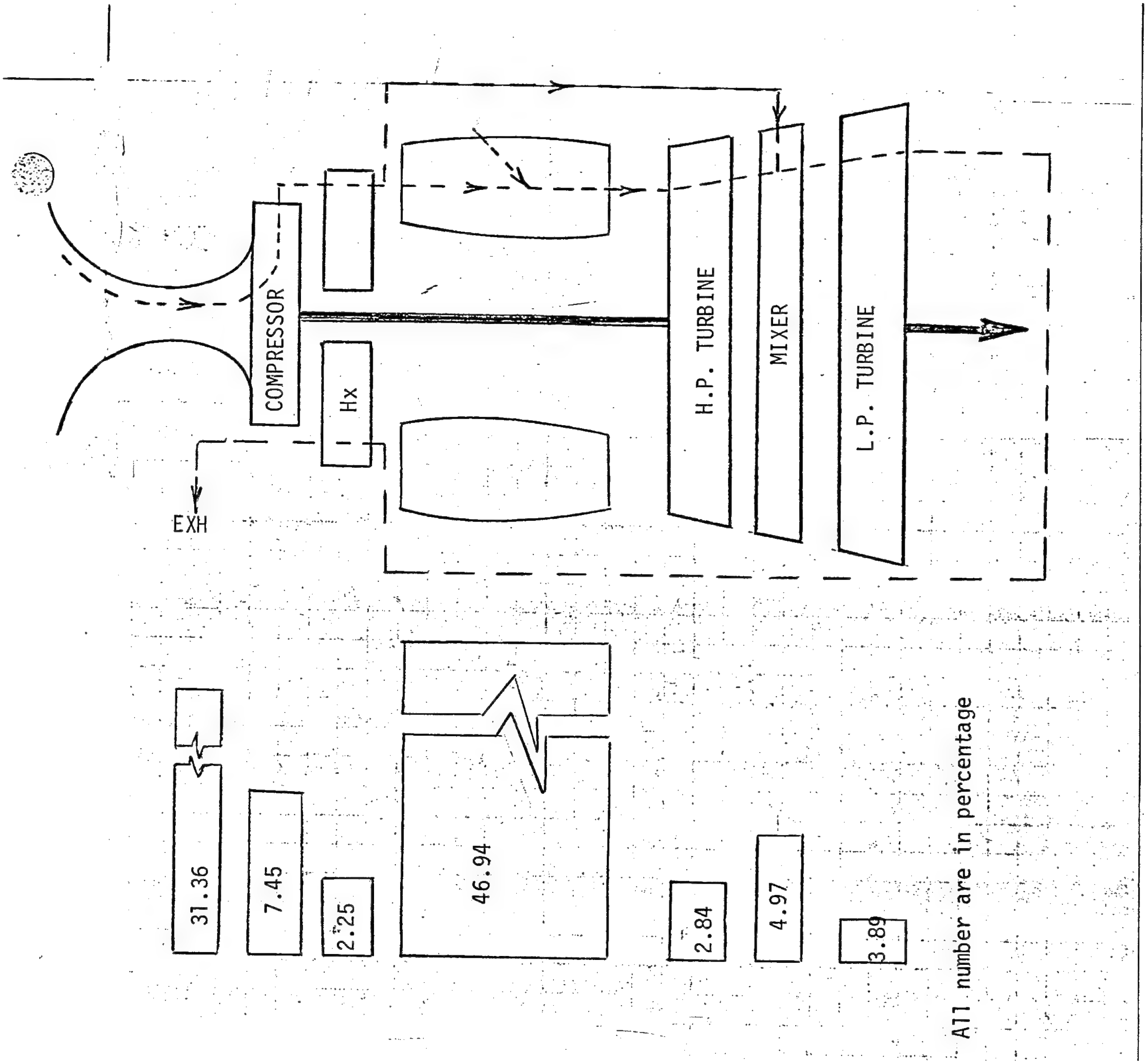


Fig. 2



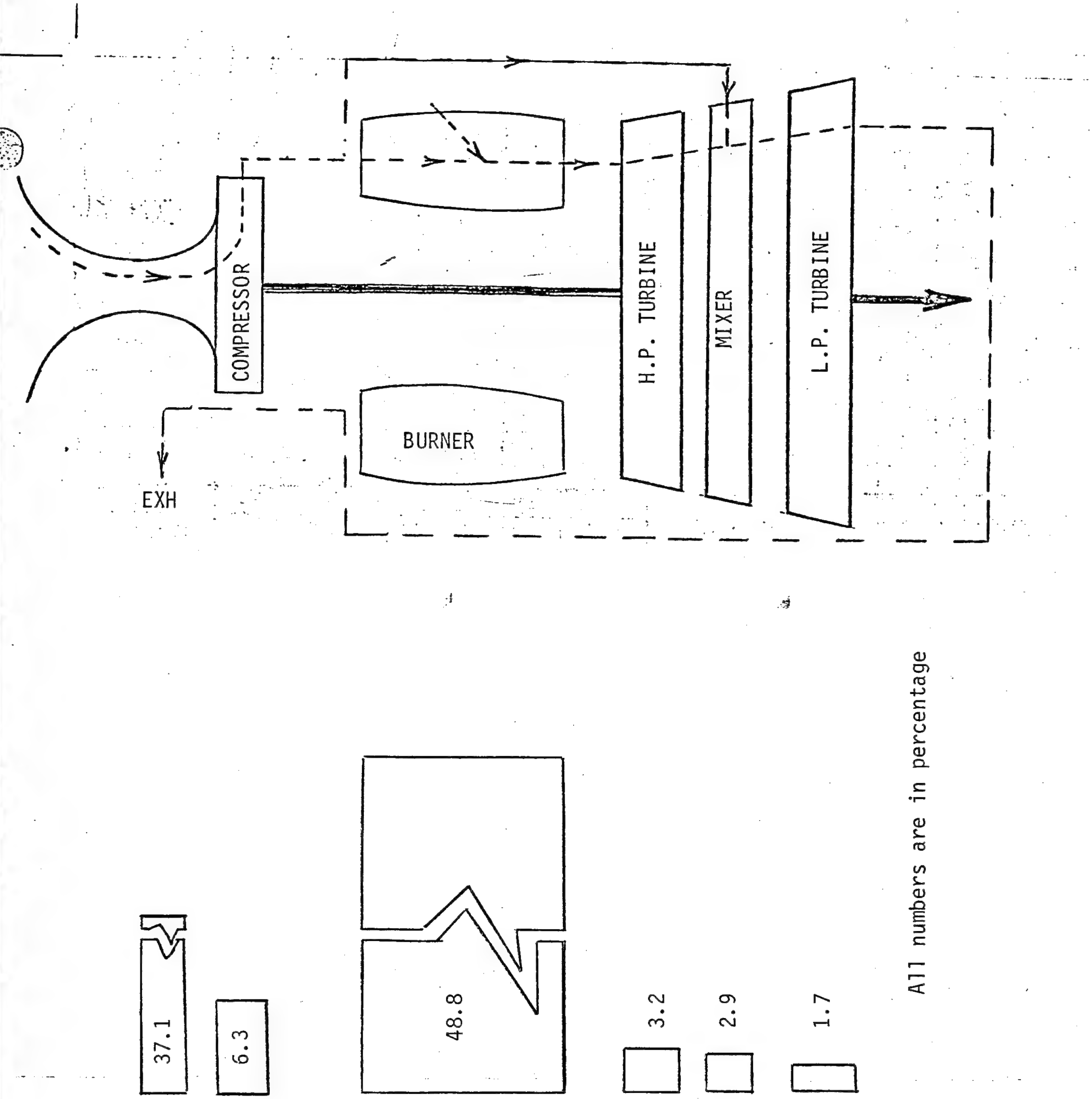
COMPARISON OF EXERGY DISSIPATION FOR $GTF990WR_{86}$ and $GTF40WR_{86}$

Fig. 3



EXERGY DISSIPATION FOR GTF40WR96

Fig. 4



EXERGY DISSIPATION FOR GTF990

Fig. 5

Conclusions and Recommendations

The exergetic methods clearly indicate areas of exergy dissipation. As is well known, the two main dissipators are the burner and the exhaust stream. The use of the regenerator reduces the loss but not enough to feel that efforts can cease in that area. The quality of the energy in the exhaust stream, even with a regenerator, is still high. In addition to some of the other well known approaches to using the exhaust stream, it may be possible to combine some of it with the fuel forming a lower grade of combustible reactants which would still perform satisfactorily in the turbines. If feasible, this would certainly reduce some of the losses.

This approach can be effectively used to compare large energy users and it is recommended that present computer programs be modified to incorporate exergy calculations as well as those of energy.

APPENDIX A

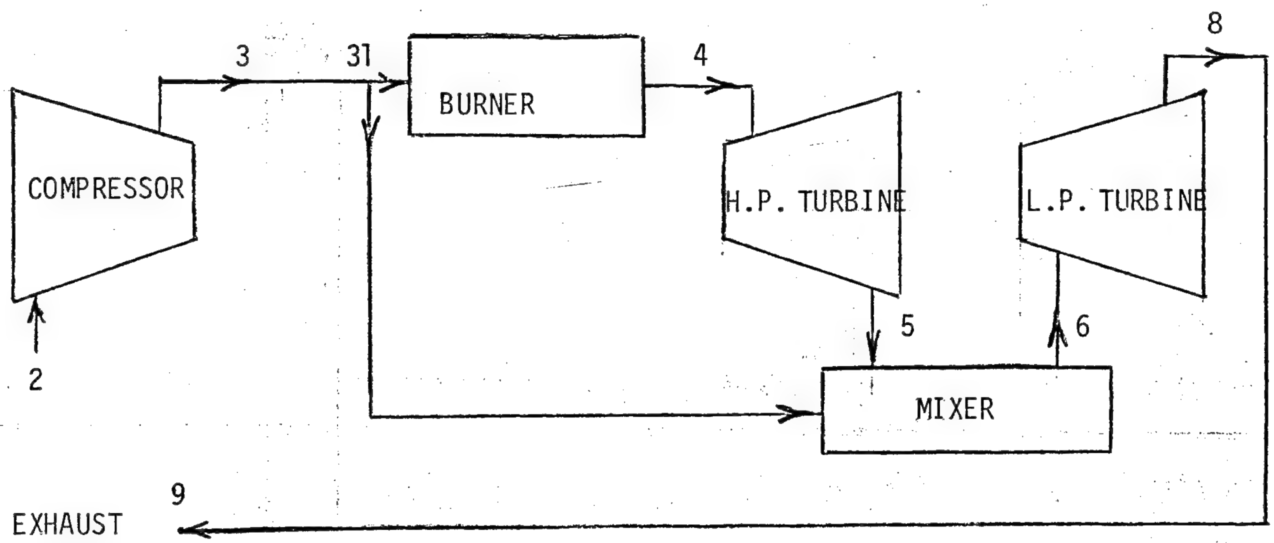
CALCULATIONS AND RESULTS

GTF990 ($C_{10}H_{22}$ as fuel)

GAS TURBINE GTF990

For this analysis $C_{10}H_{22}$ was used as the fuel. T_0 = 518.7°R, P_0 = 14.7 psia F.A.R. = .0187 → 357% of theoretical air.

The JANAF tables were used for the burner only. The calculator valves (derived from GAS TABLES) were used for all other calculations. The results were adjusted to make them consistent and then plotted.



Station	T °R	P	h	ϕ	$-R\ln\frac{P}{14.7}$	S
1	518.7	14.7	123.93	1.5910	0	1.5910
2	518.7	14.7	123.93	1.5910	0	1.5910
3	1173.4	177.1	284.44	1.7904	-.1706	1.6198
4	2358.0	171.5	619.86	1.9883	-.1696	1.8187
5	1741.7	38.3	442.53	1.9014	-.0661	1.8353
6	1683.5	38.3	425.35	1.8911	-.0661	1.8250
8	1355.2	14.7	336.23	1.8323	0	1.8323
9	1355.2	14.7	336.23	1.8323	0	1.8323

$$C_{10}H_{22} + 55.34\ O_2 + 208.06\ N_2 \rightarrow 10\ CO_2 + 11\ H_2O + 38.84\ O_2 + 208.06\ N_2$$

Molecular Weight of Products

Using 357% theoretical air - 267.9 moles of products

	x_i	M	
CO_2	.0373	44.01	1.6428
H_2O	.0411	18.02	.7399
O_2	.1450	32	4.6393
N_2	.7766	28.01	21.7519

$\hat{M}$ = 28.774 lb/lb mole of products

PRELIMINARIES

$ex = (h - T_0 S) - (h_0 - T_0 S_0)$

For this calculation: Use $T_0 = 518.7°R$

$P_0 = 14.7$ psia

Air $h_0 = 123.93$

$\phi_0 = S_0 = 1.5910$ $\therefore h_0 - T_0 S_0 = \underline{\underline{-701.32}}$ Air

Prod. of Comb

FAR = $h_0 = 124.78$

.0166 $\phi_0 = S_0 = 1.5912$ $h_0 - T_0 S_0 = \underline{\underline{-700.57}}$ FAR = .0166

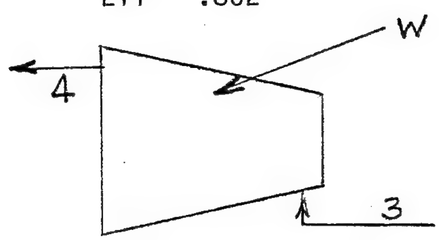
FAR = $h_0 = 124.91$

.0187 $\phi_0 = S_0 = 1.5912$ $h_0 - T_0 S_0 = \underline{\underline{-700.4}}$ FAR = .0187

STATION	$h - T_0 S$	$-[h_0 - T_0 S_0] = Ex$
1	-701.32	0
2	-701.32	0
3	-555.75	+145.57
4	-323.76	+376.55
5	-509.44	+190.96
6	-521.28	179.29
8	-614.18	86.39
9	-614.18	86.39

COMPRESSOR

Eff = .802



$W_{act} = h_3 - h_2$

$= 284.44 - 123.93$

$= 160.51$ B/1bm

$Ex_{comp} = ?$

$$\dot{Ex}_2 + \dot{Ex}_{\dot{W}} = \dot{Ex}_3 + \dot{Ex}_D$$

$$m[(h_2 - T_oS_2) - (h_o - T_oS_o)] + \dot{W} = \dot{m}[(h_3 - T_oS_3) - (h_o - T_oS_o)] + \dot{Ex}_D$$

$$[123.93 - 518.7 \times 1.5910]\ 43.5 + 43.5\ (160.51) =$$

$$[(284.44 - 518.7 \times 1.6198)]\ 43.5 + \dot{Ex}_D$$

$$(-701.32)(43.5) + 43.5\ (160.51) = (-555.75)\ 43.5 + \dot{Ex}_D$$

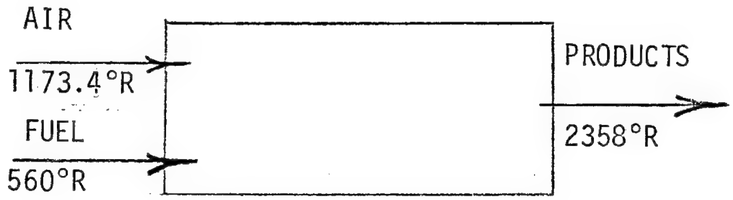
$$\underline{\underline{Ex_D = 649.9 \text{ B/s}}} \leftarrow$$

$$\dot{Ex}_2 = 43.5[(-701.32) - (-701.32)] = 0$$

$$\dot{Ex}_W = (160.51)(43.5) = 6982.2 \text{ B/s}$$

$$\dot{Ex}_3 = 43.5[(-555.75) - (-701.32)] = 6332.3 \text{ B/s}$$

COMBUSTOR (BURNER)

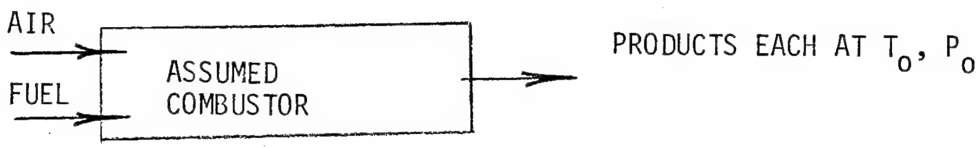


FAR = .0187 $\therefore$ 357% Theoretical Air

Combustion equation:

$$C_{10}H_{22} + 55.34\ O_2 + 208.06\ N_2 \rightarrow 10\ CO_2 + 11\ H_2O + 38.84\ O_2 + 208.06\ N_2$$

EXERGY OF REACTANTS



$$\sum_R \dot{n}_i[(h_f^{\bullet} + \Delta h) - T_oS] = \dot{Ex}_R + \Sigma n_j[(h_f^{\bullet} + \Delta h) - T_oS_o]$$

REACTANTS

$C_{10}H_{22}$: $1[-72.875 \times 1.8001 + (76.12)(23)] = -129{,}432B - T_oS = -198{,}187B$

$$T_oS = 518.7[3.9006 \frac{kJ}{kg\text{-}°k} \times .4299 \times \frac{5}{9} \times 142.286] = 68755$$

$$O_2 = \frac{55.34}{264.4} \times 177.1 = 37.07 \text{ psi}$$

$$N : = \frac{208.06}{264.4} \times 177.1 = 139.43 \text{ psi}$$

$$O_2: \quad 55.34\ [4704 - 518.7 \times (54.72 - R\ell n \frac{37.07}{14.7})] = 1257593 \text{ Btu}$$

$$N: \quad 208.06\ [4506 - 518.7 \times (51.267 - R\ell n \frac{139.43}{14.7}) = 4113071 \text{ Btu}$$

Products at T_0P_0 (H_20 liquid)

CO_2: $10[-169,297 + (-147) - 518.7\ (50.74)] = -1,957,628$

H_20: $11[-122,971 + (-18 \times 18) -518.7\ (16.716 - .614)] = -1,448,118$

corr. for S: $.08775 - .05362 = .-3413 \frac{B}{lb} \times \frac{18\ lb}{lb\ mole} = .614$

0_2: $38.84[0 + (-123) - 518.7\ (48.725)] = -986,406$

N_2: $208.06[0 + (-123) - 518.7\ (45.492)] = \underline{-4935121}$

$\Sigma = 9327273$

$\therefore$ Ex_R of REACTANTS = $\underline{3,758,422}$ B/mole fuel

= 26,415 B/lb fuel = $\underline{\underline{19018\ B/s}}$

EXERGY OF PRODUCTS

$$\rightarrow 10\ CO_2 + 11\ H_2O + 38.84\ O_2 + 208.06\ N_2$$

at $T = 2358°R$ and $P = 171.5$ psia

	x_i	$p_i = x_i P$
CO_2	.0373	6.36
H_2O	.0411	7.05
O_2	.1450	24.87
N_2	.7766	133.19

$R = 1.986 \frac{\text{Btu}}{\text{lbmole °R}}$

CO_2: $10[(-169{,}297 + 21{,}825) - 518.7\ (67.943 - \bar{R}\ell n \frac{6.36}{14.7})] = -1{,}835{,}771$

H_2O: $11[(-104{,}036 + 16{,}932) - 518.7\ (58.368 - \bar{R}\ell n \frac{7.05}{14.7})] = -1{,}299{,}500$

O_2: $38.84[(0 + 14{,}503) - 518.7\ (60.48 - \bar{R}\ell n \frac{24.87}{14.7})] = -634{,}114$

N_2: $208.06[(0 + 13{,}700) - 518.7\ (56.665 - \bar{R}\ell n \frac{133.19}{14.7})] = -2{,}792{,}536$

$= -6{,}561{,}922$ Btu

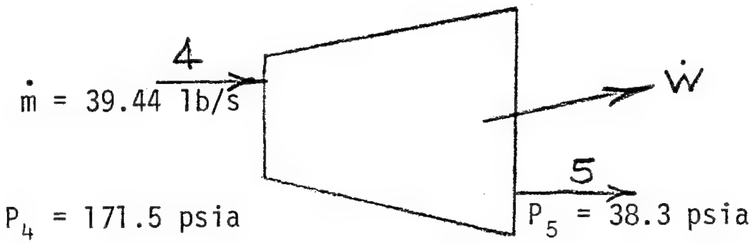
Ex of Products $= (h - T_oS) - (h_o - T_oS_o)_{T_oP_o}$

Ex_P = 2,765,350 B/mole fuel = 19,435 B/lb fuel = <u>13,993 B/s</u>

Ex_{Des} in Combustor = 3,758,422 - 2,765,350

= 993,072 B/mole fuel = 6,979 B/lb fuel = <u>5025 B/s</u>

H. P. TURBINE



Assuming adiabatic & eff = .867

$$\text{eff} = .867 = \frac{W_{act}}{W_{isen}}$$

$T_4 = 2358.0°R$ $\qquad h_4 = 619.71$ $\qquad \phi = 1.9883$

$P_5 = 38.3$ $\quad$ if $\quad S_4 = S_5 = 1.9883 - \dfrac{1.986}{28.77 \frac{\text{lb}}{\text{lbmole}}} \dfrac{\text{B}}{\text{lbmole °R}} \ln \dfrac{171.5}{14.5}$

$S_4 = 1.8187 = 1.819$

$\dfrac{P_4}{P_5} = \dfrac{P_{r4}}{P_{r5}}$: $\dfrac{171.5}{38.3} = \dfrac{395.3}{P_{r5}}$ $\qquad \therefore P_{r_5} = 88.3$

2358

P_r @ 400% = 385.1 $\qquad$ 47.3 $\qquad \therefore P_r = 395.3$

200% = 432.4

$P_r = 88.3$ @ 400% $\qquad T = 1654$ $\qquad T_s = 1647.6$ $\qquad h_s = 416.4$

200% $\qquad T = 1624$ $\qquad \phi = 1.8860$

Check $\quad S = 1.886 - \dfrac{1.986}{28.774} \ln \dfrac{38.3}{14.7} = 1.8199 \simeq 1.820$

$W_s = 619.7 - 416/4 = 203.3$

$W_a = (-867)(203.3) = 176.3$ B/lb ←

From data $\quad W_a = 619.7 - 442.5 = 177.2$ ←

∴ Data must assume adiabatic turbine.

H.P. TURBINE

$$\dot{Ex}_4 = (h_4 - T_oS_4) - (h_o - T_oS_o)$$

$$= [(619.71 - 518.7 \times 1.819) - (-700.4)]\ 39.44$$

$$= 14{,}853 \text{ B/s}$$

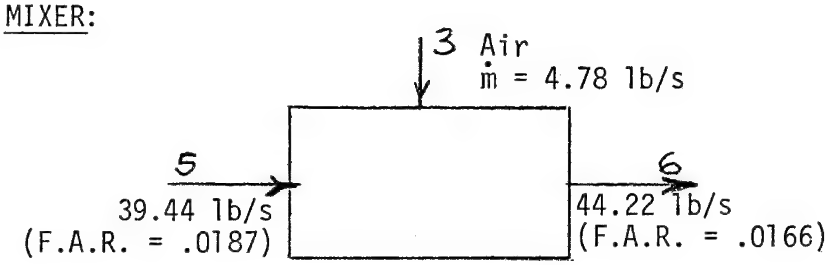
$$\dot{Ex}_W = (177.2)(39.44) = 6989 \text{ B/s}$$

$$\dot{Ex}_5 = 39.44[442.53 - 518.7 \times 1.835 - (-700.4)] = 7533 \text{ B/s}$$

$$\therefore\ 14{,}853 = 6989 + 7533 + \dot{Ex}_D$$

$$\underline{\underline{\dot{Ex}_D = 331 \text{ B/s}}}$$

MIXER:



$$\dot{Ex}_3 = 4.78\ [(-555.75) - (-701.32)] = 696 \text{ B/s}$$

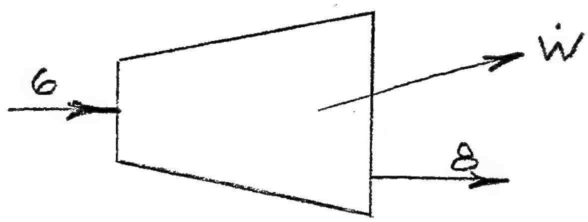
$$\dot{Ex}_5 = 7533 \text{ B/s}$$

$$\dot{Ex}_6 = 44.22\ [(425.35) - (518.7)(1.825) - (-700.57)]$$

$$= 7928 \text{ B/s}$$

$$\therefore\ 7533 + 696 = 7928 + Ex_D \qquad \therefore\ \underline{\underline{\dot{Ex}_D = 301 \text{ B/s}}}$$

L.P. TURBINE



$$W = h_6 - h_8 = 425.35 - 336.23 = 89.12 \text{ B/lb}$$

$$\dot{W} = 44.22 \times 89.12 = 3932 \text{ B/s}$$

$$\dot{Ex}_W = 3932 \text{ B/s}$$

$$\dot{Ex}_6 = 7928 \text{ B/s}$$

$$\dot{Ex}_8 = 44.22\ [(336.23 - 518.7 \times 1.8323) - (-700.57)]$$

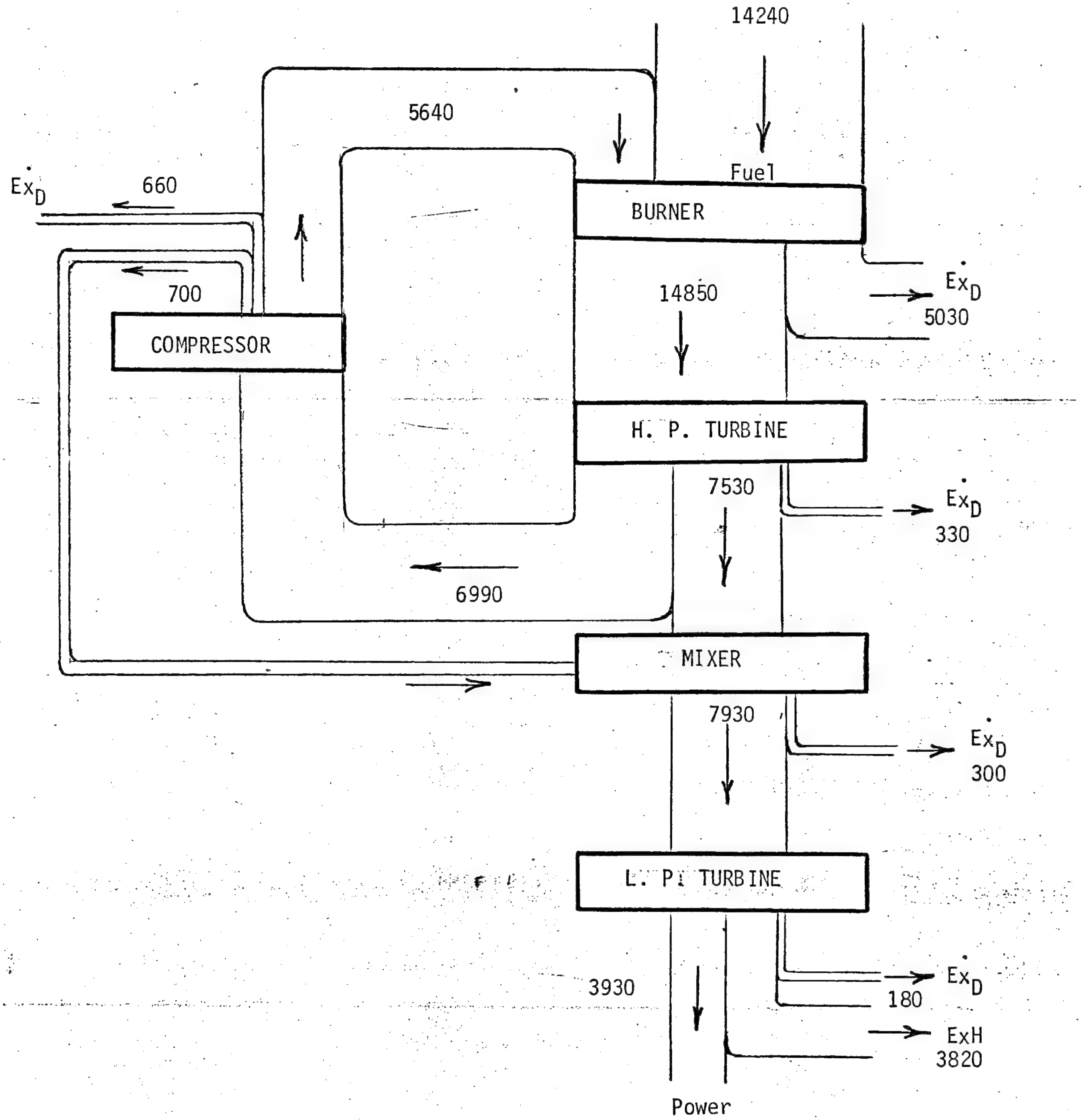
$$= 3820 \text{ B/s} \quad \text{To Dif \& Exhaust}$$

$$\therefore\ 7928 = 3932 + 3820 + \dot{Ex}_D$$

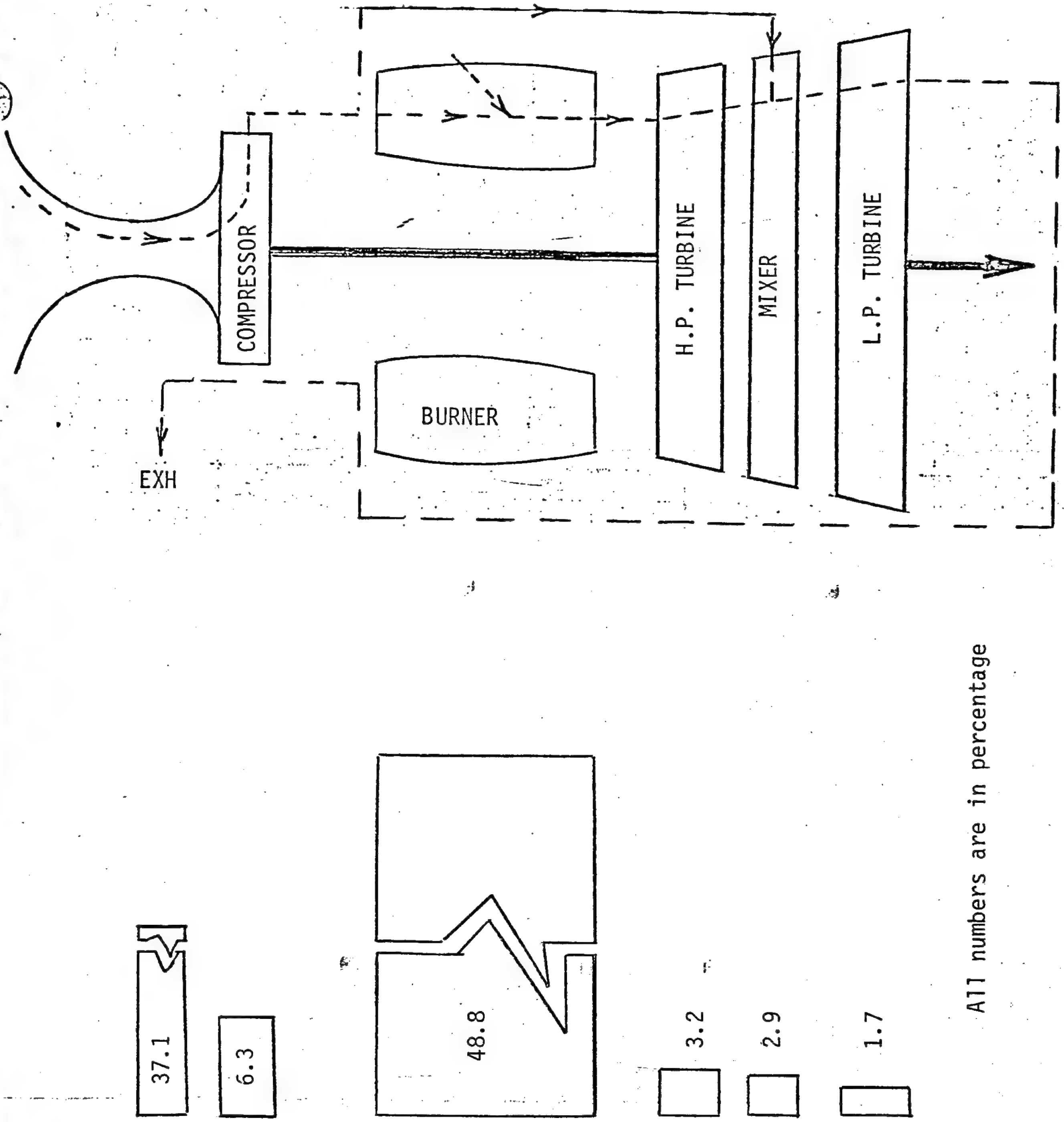
$$\dot{Ex}_D = 176 \text{ B/s}$$

EXERGY DISSIPATED

		Percent
COMP	650	6.31
BURNER	5025	48.77
H.P. TURBINE	331	3.21
MIXER	301	2.92
L.P. TURBINE	176	1.71
DIF & EXHAUST	3820	37.08
	10303 B/s	100.00



EXERGY FLOW GTF990
(All Units BTU/S)



EXERGY DISSIPATION FOR GTF990

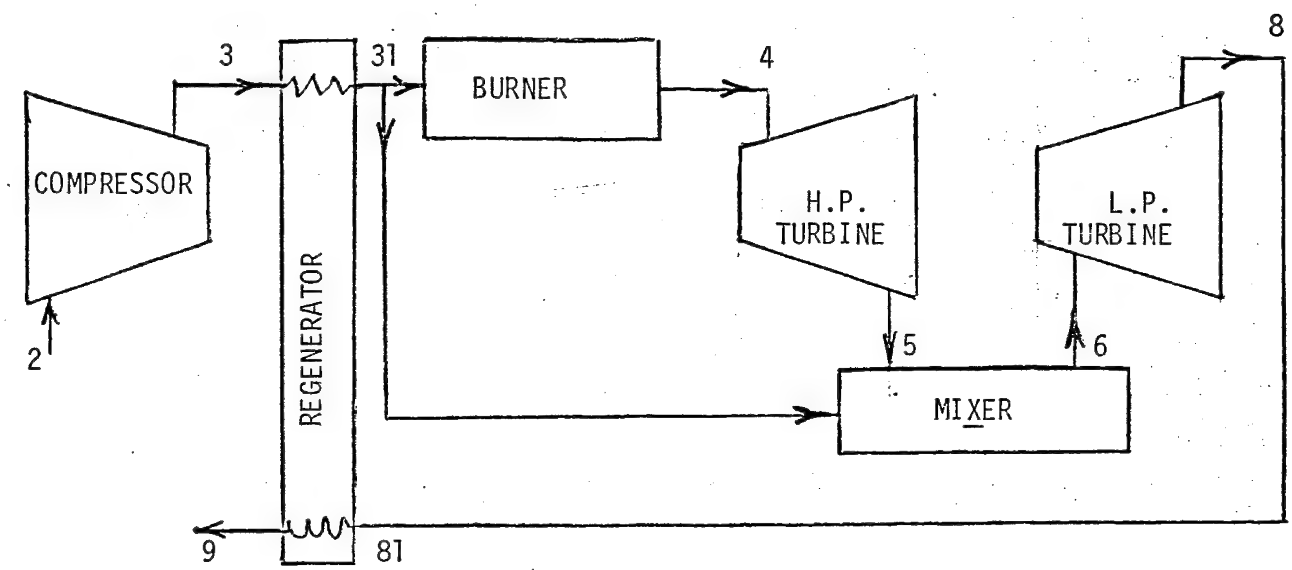
APPENDIX B

CALCULATIONS AND RESULTS

GTF990WR$_{86}$ ($C_{10}H_{22}$ as fuel)

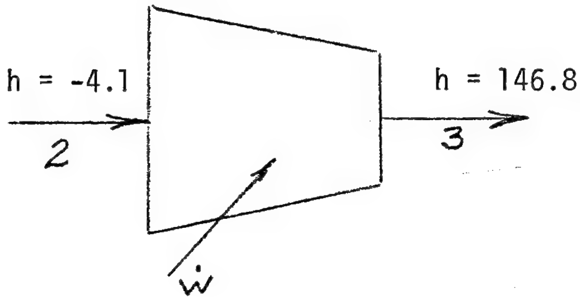
Using $C_{10}H_{22}$ Fuel GTF990WR86 JANAF DATA

AMBIENT 518.7°R & 14.7 psia



STA	P Psia	T °R	Rel to STP h B/1bm	$\dot{m}$ 1b/s	Rel to 0° ϕ B/1b-R	$R\ell n \frac{P}{14.7}$	S
2	14.7	518.7	-4.1	41.31	1.5910	0	1.5910
3	160.7	1129.7	146.8	41.31	1.7808	.1639	1.6169
31	154.2	1362.6	206.4	36.77	1.8287	.1611	1.6676
4	149.2	2358.0		37.35	1.9868	.1598	1.8270
5	38.0	1780.9		37.35	1.9065	.0655	1.8410
6	38.0	1714.1		41.90	1.8952	.0655	1.8297
8	15.4	1400.4		41.90	1.8403	.0033	1.8370
81	15.4	1400.4		41.90	1.8403	.0033	1.8370
9	14.7	1197.1		41.90	1.7990	0	1.7990

COMPRESSOR



$\therefore W = h_3 - h_2 = 150.9$ B/lb

$\dot{W} = 41.31\ (150.9)$

$= 6232$ B/s

EXERGY BALANCE

$$\dot{Ex}_2 + \dot{Ex}_W = \dot{Ex}_3 + \dot{Ex}_D$$

$$S_2 = 1.5910 - R\ln 1 = 1.5910$$

$$S_3 = 1.7808 - .06855\ \ln \frac{160.7}{14.7} = 1.6169$$

$$h_o - T_oS_o\ (@\ 14.7,\ 518.7°R) = -4.1 - 518.7 \times 1.5910$$

$$= -829.35 \text{ B/lb}$$

$$\dot{Ex}_2 = 0$$

$$\dot{Ex}_3 = \{[146.8 - 518.7 \times 1.6169] - [-829.35]\}\{41.31\}$$

$$= 5678.6 \text{ B/s}$$

$$\dot{Ex}_W = 6232 \text{ B/s}$$

$$\therefore 0 + 6232 = 5678.6 + \dot{Ex}_D$$

$$\underline{\underline{\dot{Ex}_D = 553.0 \text{ B/s}}}$$

$$\text{Cal/gm mole °K} \times 1.8001 \frac{\text{Btu/lb mole}}{\text{cal/gm mole}}\ \frac{5°K}{9°R} \times \frac{\text{lbmole}}{28.964\ \text{lbm}}$$

$\therefore$ S° @ 518.7°R = 45.99 Cal/gmole°K

= 1.588 OK

h @ 518.7 rel to 537

$$= -.065 \frac{h_{cal}}{\text{gmmole}} \times \frac{1.8001}{10^{-3}\ \frac{h_{cal}}{\text{cal}}} \times \frac{1}{28.964} = -4.07 \text{ B/lbm}$$

h @ 1129.7°R

$$= 2.322 \frac{k_{cal}}{gmmole} = 146.8 \text{ B/lbm}$$

h @ 1362.6 @ 31

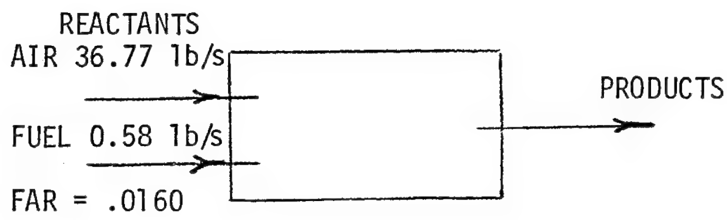
$$3.321 \frac{h_{cal}}{gmmole} = 206.4 \text{ B/lbm}$$

<u>AT 31</u> out of HX

$$\dot{Ex} = \{(206.4 - 518.7 \times 1.6676) - (-829.35)\}\ 41.31$$

$$\underline{\underline{\dot{Ex} = 7054 \text{ B/s}}}$$

BURNER



Assume $C_{10}H_{22}$ fuel $\qquad$ LHV = 19,020 B/lb

$T_{fuel} = 100°F$ $\qquad$ $C_p = .535$ B/lb °R = 76.12 B/lbmole-°R

Air Temp = 1362.6°R

$$C_{10}H_{22} + x\ 15.5\ (O_2 + 3.76N_2) \rightarrow 10\ CO_2 + ?\ 11\ H_2O + ?\ O_2 + ?\ N_2$$

$$.0160 = \frac{(1)(142.286)}{x(15.5)(32) + x\ (15.5)(3.76)(28.016)}$$

$x = 4.18 \quad \therefore \quad$ 418% theoretical Air

$\therefore$

$$C_{10}H_{22} + 64.79\ O_2 + 243.61\ N_2 \rightarrow 10\ CO_2 + 11\ H_2O + 49.29\ O_2 + 243.61\ N_2$$

$$\dot{Ex}_R = \dot{Ex}_P + \dot{E}_{xD}$$

H_R:

$C_{10}H_{22}$: $1[(-131\ 183) + 76.13\ (23)] = -129\ 432$

O_2: $64.79[0 + 6197] = 401\ 504$

N_2: $243.61[0 + 5898] = 1\ 436\ 812$

$$S_{C_{10}H_{22}} = 3.9006 \times \frac{1}{4.187} \times 142.286 = 132.553 \text{ B/lbmole °R}$$

O_2: $x_i = .21 \therefore p_{O_2} = .21 \times 154.2 = 32.38$ psia $\therefore S_{O_2} = 55.9 - 1.986 \ln \frac{32.38}{14.7} = 54.33$

N_2: $x_i = .79 \therefore p_{N_2} = .79 \times 154.2 = 121.82$ psia $\therefore S_{N_2} = 52.374 - 1.986 \ln \frac{121.82}{14.7} = 48.174$

	H_R	S	$-nT_oS$	$H_R - T_oS$
$C_{10}H_{22}$	-129432	132.553	-68755	-198 187
O_2	+401504	54.33	-1825845	-1424341
N_2	+1436812	48.174	-6087291	-4650479

$\Sigma H_R - T_oS = -6273007$ Btu

$\underline{H_o - T_oS_o \text{ of Products at STP}}$

CO_2: $10[-169{,}297 + (-147) - 518.7\ (50.742)] = -1957\ 639$

H_2O (ℓ): $11[-122971 + (-18 \times 18) - 518.7\ (16.716 - .614)] = -1448\ 118$

O_2: $49.29[0 + (-123) - 518.7\ (48.725)] = -1\ 251\ 801$

N_2: $243.61[0 + (-123) - 518.7\ (45.492)] = -5\ 778\ 356$

$(H_o - T_oS_o)_{STP} = -10\ 435\ 914$ Btu

$Ex_R = 4162\ 907$ B/mole fuel

$$\dot{m} = .58 \frac{lb_{fuel}}{S} \times \frac{mole_{fuel}}{142.286\ lb_{fuel}}$$

$$\therefore \underline{\underline{\dot{Ex}_R = 16\ 969 \text{ B/s}}}$$

PRODUCTS

CO_2: $10[(-169297 + 21825) - 518.7\ (70.183)] = -1838759$

H_2O: $11[(-104036 + 16932) - 518.7\ (60.423)] = -\ 1302900$

O_2: $49.29[(0\ \_\ 14504) - 518.7\ (59.554)] = -\ 807698$

N_2: $243.61\ [(0 + 13700) - 518.7\ (52.566)] = -\ 3304809$

ENTROPIES:

	p_i (psia)	$-R\ell n\ P/14.7$	ϕ	S
x_{CO_2} = 10/313.9 = .0319	4.759	2.240	67.943	70.183
H_2O 11/313.9 = .0350	5.222	2.055	58.368	60.4238
O_2 49.29/313.9 = 1570	23.424	- .925	60.479	59.554
N_2 243.61/313.9 = .7761	115.794	-4.099	56.665	52.566

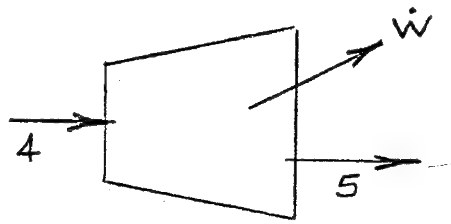
$(H - T_oS)_P = -7254167$

$Ex_P = (H - T_oS)_P - (H_o - T_oS_o)_{STP} = 3181747$ B/mole fuel

$\dot{E}x_P = 12970$ B/s $= \dot{E}x_4$

$16969 - 12970 = \underline{\underline{\dot{E}x_D = 3999 \text{ B/s} \quad \text{BURNER}}}$

H.P. TURBINE



T_5 = 1780.9°R, P_5 = 38.0 psia

$h_5 - h_4$ = 1530985 B/mole fuel

from pg 6 & 7 below.

$\dot{W}$ = 6240 B/s

Ex_5

CO_2: 10[-169.297 + 11825 - 518.7 (69.157)] = -1933437

H_2O: 11[-104036 + 10991 - 518.7 (60.256)] = -1367298

O_2 : 49.29[0 + 9611 - 518.7 (59.891)] = -1057490

N_2 : 243.61[0 + 9084 - 518.7 (53.038)] = -4488955

Σ = -8847181 Btu

	p_i	$-R\ln P/14.7$	ϕ	S
CO_2	1.212	4.956	64.201	69.157
H_2O	1.330	4.772	55.484	60.256
O_2	5.966	1.791	58.100	59.891
N_2	29.492	-1.383	54.421	53.038

Ex_5 = - 8847181 - (-10 435 914) = 1588733 B/mole fuel

CO_2	.0319	44.011	1.404
H_2O	.0350	18.016	.631
O_2	.1570	32.00	5.024
N_2	.7761	28.016	21.743

$\hat{M}$ = 28.8 lb/mole
(not needed at this time)

$\therefore Ex_5 = 1588733 \times .58 \times \frac{1}{142.286} = 6476$ B/s

$12970 = 6240 + 6476 + \dot{Ex}_D \therefore \underline{\underline{\dot{Ex}_D = 254 \text{ B/s}}}$

H.P. TURBINE (CHECK)

Using Calculator Program

$$(H - T_o S)_4 - (H_o - T_o S_o)_{4_{STP}} = (H - T_o S)_5 - (H_o - T_o S_o)_{5_{STP}} + \dot{W} + \dot{Ex}_D$$

$$H_4 - H_5 - T_o (S_4 - S_5) = \dot{W} + \dot{Ex}_D$$

$$\dot{Ex}_D = T_o (S_5 - S_4)$$

S_5 @ 1780.9°R & 38 psia

$$\phi_5 = 1.9065 \text{ B/lbm} \qquad - \frac{1.986}{28.802} \ln \frac{38}{14.7} = - .0655$$

$$S_5 = 1.8410 \text{ B/lbm}$$

S_4 @ 2358°R & 149.2 psia

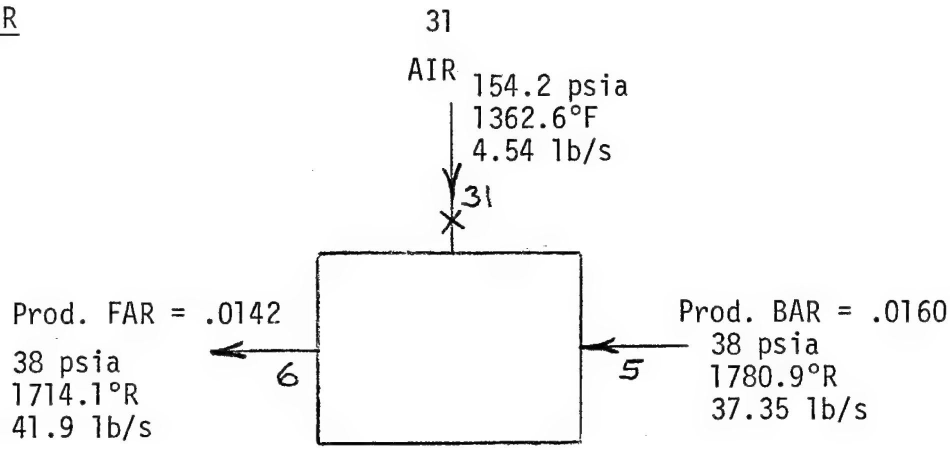
$$\phi_4 = 1.9868 \qquad - \frac{1.986}{28.802} \ln \frac{149.2}{14.7} = - .1598$$

$$S_4 = 1.8270$$

$$\therefore \dot{Ex}_D = (37.35)(518.7)(1.841 - 1.827)$$

$\underline{\underline{\dot{Ex}_D = 270 \text{ B/s}}}$ close enough

MIXER



For a FAR = .0142 must add $x(O_2 + 3.76\ N_2)$

$$.0142 = \frac{142.286}{x(15.5)(32) + x(15.5)(3.76)(28.016)} \quad \therefore\ x = 4.707$$

$$72.96\ O_2 - 64.79\ O_2 = 8.17\ O_2$$

$$274.32\ N_2 - 243.61\ N_2 = 30.71\ N_2$$

$\therefore$ AIR

$$(8.17\ O_2 + 30.71\ N_2) + 10\ CO_2 + 11\ H_2O + 49.29\ O_2 + 243.6\ IN_2$$

$$\rightarrow 10\ CO_2 + 11\ H_2O + 57.46\ O_2 + 274.32\ N_2$$

Ex air 31 (206.4 - 518.7 x 1.6676) - (-829.35)

$\phi = 1.8287$ $S = 1.6675$

$Ex_{air} = 170.76$ B/lb

$\underline{\underline{\dot{E}x_{air} = 775 \text{ B/s}}}$

$\underline{\underline{\dot{E}x_5 = 6476 \text{ B/s}}}$

Ex_6

	n	x_i	M	lb/mole mix	P_i
CO_2	10	.0283	44.011	1.2475	1.075
H_2O	11	.0312	18.016	0.5618	1.186
O_2	57.46	.1629	32	5.2121	6.190
N_2	274.32	.7776	28.016	21.7851	29.549
	352.78			28.807	

$\hat{M} = 28.81$

	ϕ	$-R\ln P_i/14.7$	S	Δh
CO_2	63.699	5.194	68.893	13270
H_2O	55.104	4.999	60.103	10344
O_2	57.776	1.718	59.494	9058
N_2	54.118	-1.387	52.731	8567

CO_2: $10[-169297 + 13270 - 518.7\ (68.893)] = -1917618$

H_2O: $11[-104036 + 10344 - 518.7\ (60.103)] = -1373542$

O_2 : $57.46[0 + 9058 - 518.7\ (59.494)] = -1252716$

N_2 : $274.32[0 + 8567 - 518.7\ (52.731)] = -5152983$

$\Sigma = (H - T_0S)_6 = -\ 9696859$ Btu

$H_0 - T_0S_0$ at STP

CO_2: $10[-169297 + (-147) - 518.7\ (50.742)] = 01957639$

H_2O: $11[-122971 + (-324) - 518.7\ (16.716 - .614)] = -1448118$

O_2 : $57.46[0 + (-123) - 518.7\ (48.725)] = -1459292$

N_2 : $274.32[0 + (-123) - 518.7\ (45.492)] = 06506788$

$\underline{Ex_6}$

	n	x_i	M	lb/mole mix	P_i
CO_2	10	.0283	44.011	1.2475	1.075
H_2O	11	.0312	18.016	0.5618	1.186
O_2	57.46	.1629	32	5.2121	6.190
N_2	274.32	.7776	28.016	21.7851	29.549
	352.78			28.807	

$\hat{M} = 28.81$

	ϕ	$-R\ell n\ P_i/14.7$	S	Δh
CO_2	63.699	5.194	68.893	13270
H_2O	55.104	4.999	60.103	10344
O_2	57.776	1.718	59.494	9058
N_2	54.118	-1.387	52.731	8567

CO_2: $10[-169297 + 13270 - 518.7\ (68.893)] = -1917618$

H_2O: $11[-104036 + 10344 - 518.7\ (60.103)] = -1373542$

O_2 : $57.46[0 + 9058 - 518.7\ (59.494)] = -1252716$

N_2 : $274.32[0 + 8567 - 518.7\ (52.731)] = -5152983$

$\Sigma = (H - T_oS)_6 = -\ 9696859$ Btu

$H_o - T_oS_o$ at STP

CO_2: $10[-169297 + (-147) - 518.7\ (50.742)] = 01957639$

H_2O: $11[-122971 + (-324) - 518.7\ (16.716 - .614)] = -1448118$

O_2 : $57.46[0 + (-123) - 518.7\ (48.725)] = -1459292$

N_2 : $274.32[0 + (-123) - 518.7\ (45.492)] = 06506788$

Line 6 con't

$$\Sigma = -\ 11371837\ B = H_o - T_oS_o \text{ at STP}$$

$$\text{for FAR} = .0142$$

$$(H - T_oS) - (H_o - T_oS_o) = -\ 9696859 - (-11371837)$$

$$Ex_6 = 1674978\ B/352.78 \text{ moles}$$

$$= 4748\ B/\text{mole} \times \frac{\text{mole}}{28.81\ \text{lb/mole}} \times 41.9\ \frac{\text{lb}}{\text{s}}$$

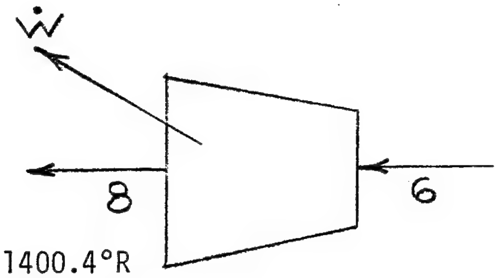
$$\underline{\underline{\dot{Ex}_6 = 6905\ B/s}}$$

∴ FOR MIXER

$$775 + 6476 = 6905 + \dot{Ex}_D$$

$$\underline{\underline{369\ B/s = \dot{Ex}_D}}$$

L.P. TURBINE



T = 1400.4°R
15.4 psia

$\dot{W} = (\Delta h)\ \dot{m}$

Δh = 874050 B/352.78 moles

$\dot{W}$ = 3603 B/s

$\underline{\dot{Ex}_8}$

	$S^\circ = \phi$	Δh	P_i	$-R\ell n\ P_i/14.7$	S
CO_2	61.167	9337	.436	6.987	68.154
H_2O	53.197	7380	.480	6.794	59.991
O_2	56.127	6499	2.509	3.511	59.638
N_2	52.580	6179	11.975	.407	52.987

$H - T_oS$

CO_2: $10[-169297 + 9337 - 518.7\ (68.154)] = -1953115$

H_2O: $11[-104036 + 7380 - 518.7\ (59.991)] = -1405506$

O_2 : $54.76[0 + 6499 - 518.7\ (59.638)] = -1404048$

N_2 : $274.32[0 + 6179 - 518.7\ (52.987)] = -5844486$

$$H - T_oS = -10607155$$

$Ex_8 = -\ 10607155 - (-11371837) = 764682$ B

$$\dot{Ex}_8 = 764682 \times \frac{1}{352.78} \times \frac{1}{28.81} \times 41.9$$

$\underline{\dot{Ex}_8 = 3152 \text{ B/s}}$

$6905 = 3603 + 3152 + Ex_D$

$\underline{\underline{Ex_D = 150 \text{ B/s}}}$

HEAT EXCHANGER

$T_9 = 1197.1°R \quad P_9 = 14.7$

<u>LINE 9</u>

		$-R\ell n \frac{P_i}{14.7}$	S	Δh
CO_2	59.287	7.080	66.367	6913
H_2O	51.774	6.886	58.660	5548
O_2	54.878	3.604	58.482	4889
N_2	51.414	,500	51.914	4677

CO_2: $10[-169297 + 6913 - 518.7\ (66367)] = -1968086$

H_2O: $11[-104036 + 5548 - 518.7\ (58.660)] = -1418064$

O_2 : $57146[0 + 4889 - 518.7\ (58.482)] = -1462105$

N_2 : $274.32[0 + 4677 - 518.7\ (51.914)] = -6103837$

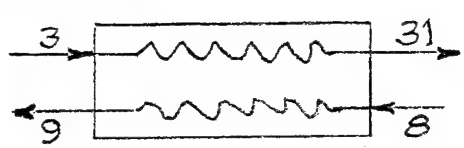
$(H - T_oS)_9 = -10952092$ Btu

$(H_o - T_oS_o) = -11371837$ Btu

$Ex_9 = 419745$ Btu

$$\dot{Ex}_9 = 419745 \times \frac{1}{352.78} \times \frac{1}{28.81} \times 41.9$$

$\underline{\underline{\dot{Ex}_9 = 1730 \text{ B/s}}}$

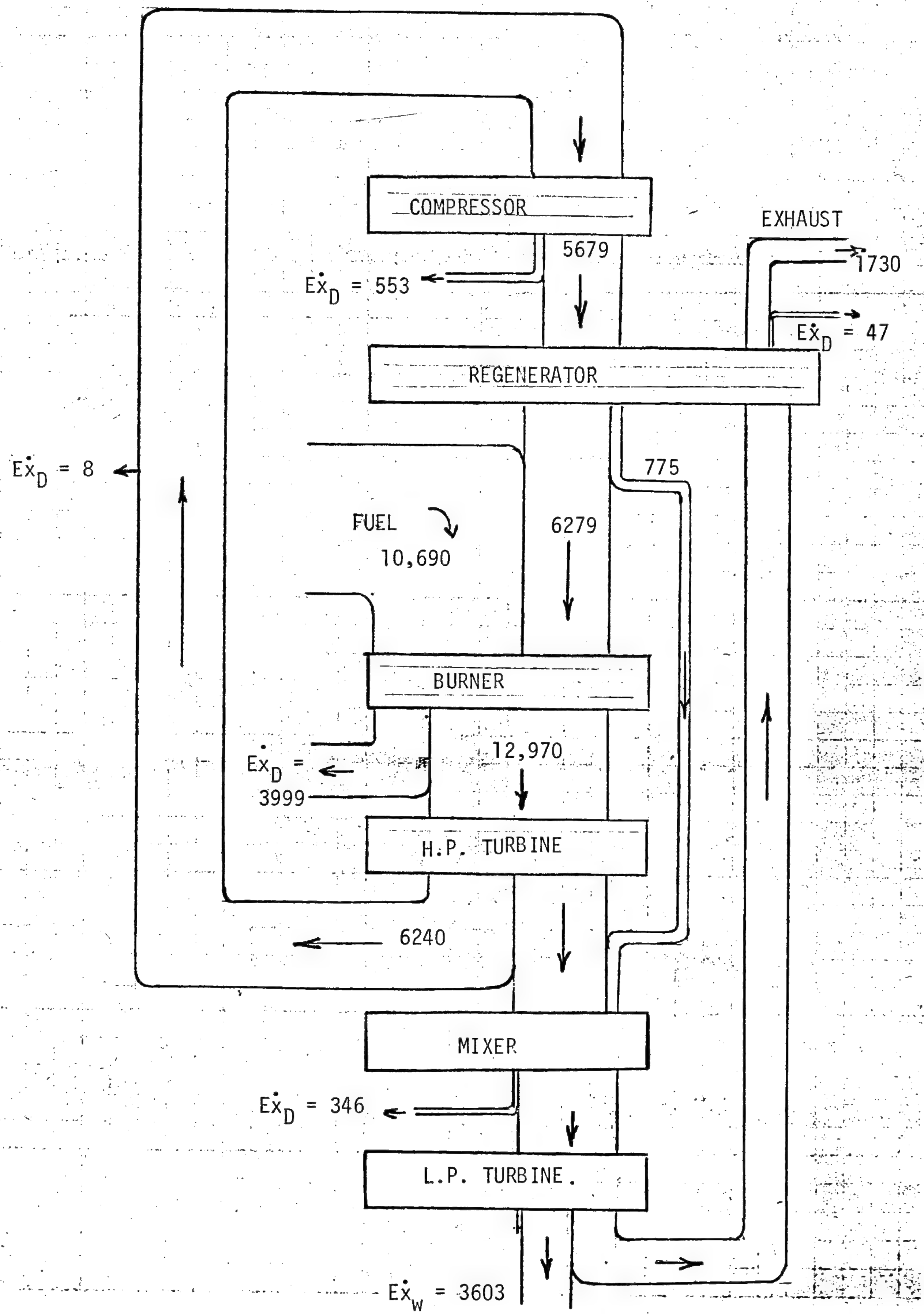


$$\dot{Ex}_3 + \dot{Ex}_8 = \dot{Ex}_{31} + \dot{Ex}_9 + \dot{Ex}_D$$

$$5679 + 3152 = 7054 + 1730 + \dot{Ex}_D$$

$\underline{\underline{\dot{Ex}_D = 47 \text{ B/s}}}$

EXERGY FLOW DIAGRAM
(All values in Btu/s)



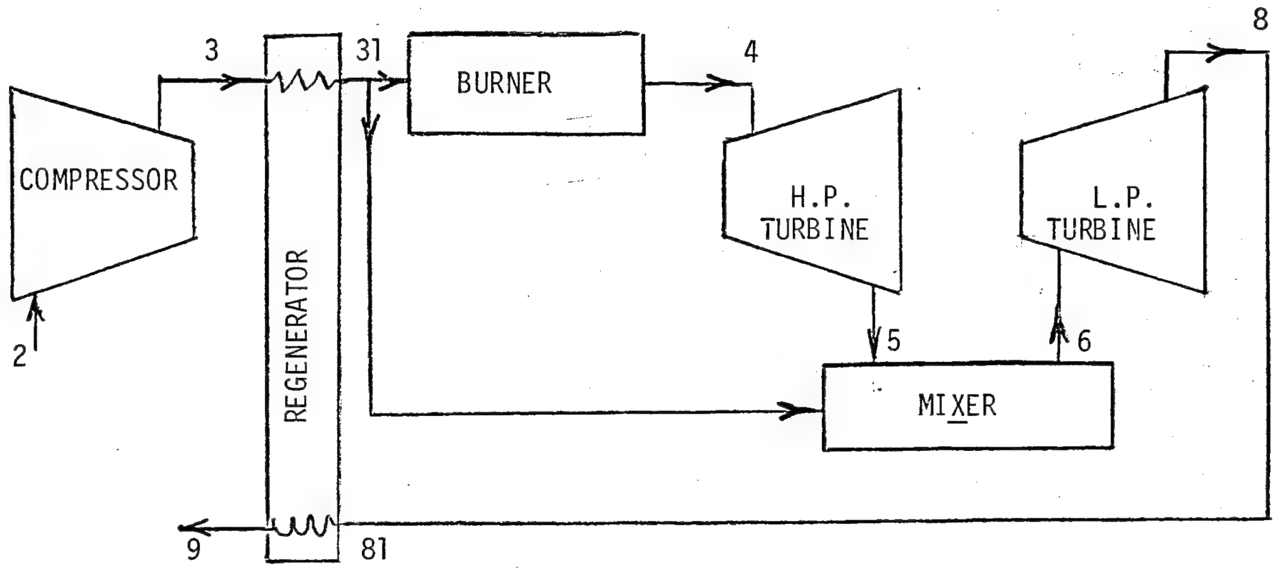
APPENDIX C

CALCULATIONS AND RESULTS

$GTF990WR_{86}$ and $GTF40WR_{86}$ (LHV = 18,400 Btu/lbm)

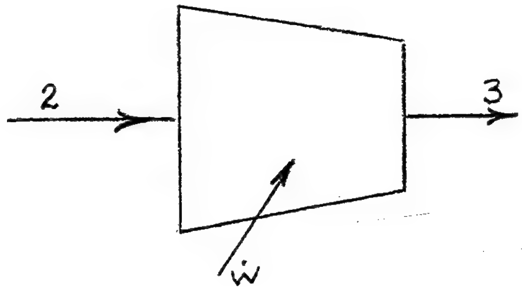
USING GAS TABLES

Ambient 518.7°R & 14.7 psia; REF. EFF = .86; LH.V. = 18,400 Btu/lbm



STA	P Psia	T °R	h Btu/lbm	$\dot{m}$ lbm/s	ϕ	Rℓn P/14.7	S
2	14.7	418.7	123.93	41.31	1.5910		1.5910
3	160.7	1129.7	273.10	41.31	1.7808	.1639	1.6169
31	154.2	1362.6	332.70	36.77	1.8287	.1611	1.6676
4	149.2	2358.0	617.52	37.35	1.9868	.1598	1.8270
5	38.0	1780.0	452.14	37.35	1.9065	.0655	1.8410
6	38.0	1714.1	432.69	41.90	1.8952	.0655	1.8297
8	15.4	1400.4	347.47	41.90	1.8403	.0033	1.837
81	15.4	1400.4	347.47	41.90	1.8403	.0033	1.8370
9	14.7	1197.1	293.97	41.90	1.7990	0	1.7990

COMPRESSOR



$\dot{W} = 6162.2$ Btu/s

$\dot{m} = 41.31$ lbm/s

$$E\dot{x}_2 + E\dot{x}_W = E\dot{x}_3 + E\dot{x}_D$$

$$E\dot{x}_2 = 0$$

$$E\dot{x}_W = 6162.2 \text{ Btu/s}$$

$$h_o - T_o S_o = 123.93 - 518.7 \times 1.5910$$

$$= -701.32 \text{ Btu/lbm (@14.7 \& 518.7°R)}$$

$$E\dot{x}_3 = \{[273.1 - 518.7 \times 1.6169] - [-701.32]\}\{41.31\}$$

$$= 5607.2 \text{ Btu/s}$$

$$\therefore\ 0 + 6162.2 = 5607.2\ E\dot{x}_D$$

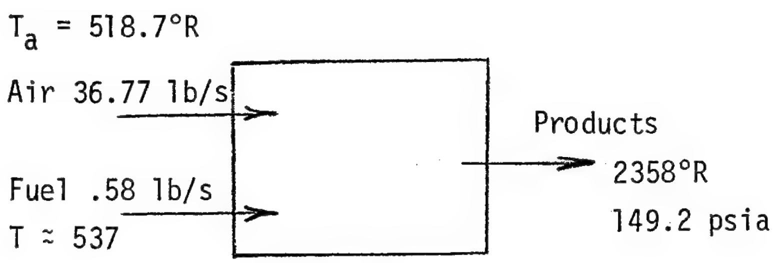
$$\underline{\underline{E\dot{x}_D = 555 \text{ Btu/s}}}$$

$E\dot{x}_{31}$ (out of HX)

$$E\dot{x} = \{[33].7 - 518.7 \times 1.6676] - [-701.32]\}\{41.31\}$$

$$E\dot{x}_{31} = 6983 \text{ Btu/s}$$

BURNER



T_{air} = 1362.6°R

T_o = 518.7°R

LHV = 18400 Btu/lbm

$S°_{fuel}$ = .9 Btu/lbm °R

$$\dot{Ex}_D = \dot{m}_f\,(LHV) + \dot{m}_f\,(\Delta h_f - T_oS_f) + \dot{m}_{air}\,(\underset{T_a - 537}{\Delta h - T_oS})_{air}$$

$$- \dot{m}_p\,(\Delta h_p - T_oS)_p$$

$\dot{m}_f$ (LHV) = (.58)(18,400) = <u>10672 B/s</u>

$\Delta h_f \approx 0$, $T_o\ S_f$ = (518.7)(.9) = 467 B/lb; $\dot{m}_f$ (   ) = 271 B/s

Δh_{arm} = (333 - 128) = 205 B/lbm; T_oS = 518.7 x 1.6676 = 865 B/lbm

$\therefore\ \dot{m}_{air}\,(\Delta h - T_oS)$ = -24266 B/s

Δh_p = (617.5 - 129.2) = 488.3 B/lbm; $T_oS_p = 518.7\ (1.9868 - R\ell n\ \frac{149.2}{14.7})$

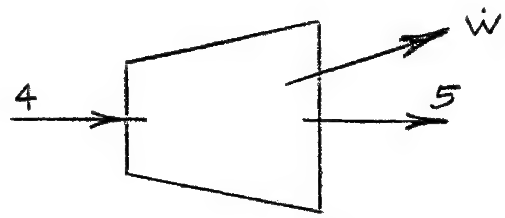
T_oS_p = 518.7 (1.9868 - .1598) = 947.7 B/lb

$\dot{m}_p\,(\Delta h_p - T_oS)_p$ = 37.35 (488.3 - 947.7) = -17157 B/s

$\dot{Ex}_D$ = 10672 - 271 + (-24266) - (-17157)

$$\underline{\underline{\dot{Ex}_D = 3292\ B/s}}$$

H.P. TURBINE



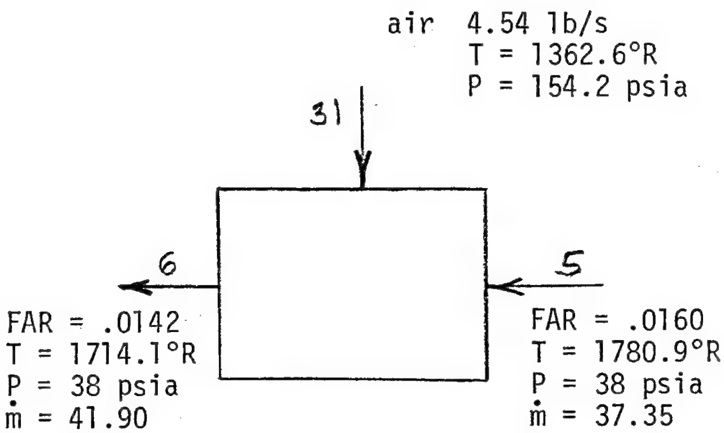
$\dot{W} = 6177$ B/s

$$\dot{Ex}_4 - \dot{Ex}_5 - \dot{W} = \dot{Ex}_D$$

$$37.35\ [(617.52 - 518.7 \times 1.827) - (452.14 - 518.7 \times 1.841)] - 6177 = \dot{Ex}_D$$

$$37.35\ [172.64] = 6177 = \underline{\underline{271 \text{ B/s} = \dot{Ex}_D}}$$

MIXER



$$(h_o - T_oS_o)_{31} = 123.78 - 518.7 \times 1.5910; \quad (h - T_oS)_{31} = 332.70 - 518.7 \times 1.6676$$

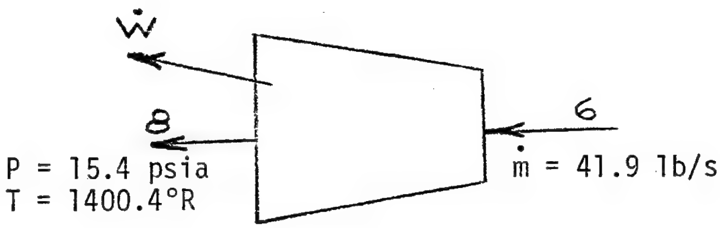
$$(h_o - T_oS_o)_5 = 124.75 - 518.7 \times 1.5912; \quad (h - T_oS)_5 = 452.14 - 518.7 \times 1.841$$

$$(h_o - T_oS_o)_6 = 124.64 - 518.7 \times 1.5912; \quad (h - T_oS)_6 = 432.69 - 518.7 \times 1.8297$$

$$\dot{Ex}_D = 4.54\ [169.2] + 37.35\ [197.82] - 41.9\ [184.34]$$

$$\underline{\underline{\dot{Ex}_D = 433 \text{ B/s}}}$$

L.P. TURBINE



$$\dot{Ex}_D = \dot{Ex}_6 - \dot{Ex}_8 - \dot{W}$$

$$\dot{Ex}_D = 41.9\ [(432.69 - 518.7 \times 1.8297) - (347.47 - 518.7 \times 1.837)] - 3571 \text{ B/s}$$

$$\dot{Ex}_D = 41.9\ [518.7(1.837 - 1.8297)] = \underline{\underline{158 \text{ B/s}}}$$

HEAT EXCHANGER

$$\dot{Ex}_D = T_0\ (\Sigma\Delta S)$$

$$= 518.7\ [(1.6676 - 1.6169)\ 41.31 + (1.7990 - 1.837)\ 41.9]$$

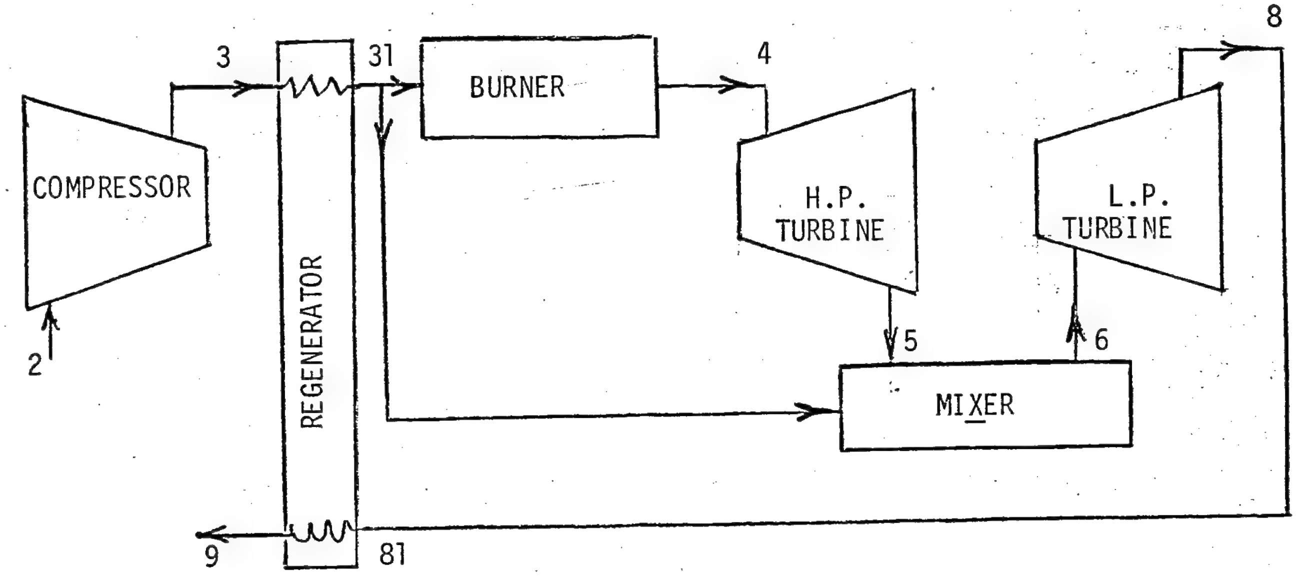
$$\underline{\underline{\dot{Ex}_D = 262 \text{ B/s}}}$$

$$Ex_9 = 41.9\ [(293.97 - 518.7 \times 1.7990) - (124.64 - 418.7 \times 1.5912)]$$

$$\underline{\underline{Ex_9 = 2579 \text{ B/s}}}$$

SUMMARY

		PERCENT	
		(%)	(%) not counting burner
COMPRESSOR	555	7.35	13.03
BURNER	3292	43.60	-
H.P. TURBINE	271	3.59	6.36
MIXER	433	5.73	10.17
L.P. TURBINE	158	2.09	3.71
HEAT EXCHANGER	263	3.48	6.18
EXHAUST	2579	34.15	60.55



STATION	TEMP R	PRESS PSI	ENTH BTU/LB	FAR	MASSFLOW LB/SEC	S°	$R \ln \frac{P}{14.7}$	s
2	560.0	14.6	133.65		29.00	1.6094	0	1.6094
3	1107.6	119.4	267.53		27.55	1.7758	.1435	1.6323
31	1532.0	118.6	377.51		27.55	1.8595	.1430	1.7165
4	2414.7	113.9	633.07	.0144	27.95	1.9929	.1405	1.8524
5	1931.9	39.2	494.02	.0144	27.95	1.9287	.0673	1.8614
6	1893.8	37.6	482.87	.0137	29.40	1.9228	.0644	1.8584
8	1601.1	16.1	401.71	.0137	29.40	1.8763	.0062	1.8701
81	1601.1	15.8		.0137	29.40	1.8763	.0050	1.8713
9	1206.4	14.9	296.25	.0137	29.40	1.8009	.0009	1.8000

Compressor

$$\dot{Ex}_D = 29(518.7)(1.6323 - 1.6094) = \underline{\underline{344\ B/s}}$$

H.P. Turbine

$$\dot{Ex}_D = 27.95(518.7)(1.8614 - 1.8524) = \underline{\underline{130\ B/s}}$$

L.P. Turbine

$$\dot{Ex}_D = 29.4(518.7)(1.8701 - 1.8584) = \underline{\underline{178\ B/s}}$$

HEAT EXCH

$$\dot{Ex}_D = 518.7\ [29(1.7165 - 1.6323) + 29.4\ (1.8000 - 1.8713)]$$

$$\dot{Ex}_D = \underline{\underline{179\ B/s}}$$

BURNER

$$\dot{Ex}_D = \dot{m}_f\ (LHV) + \dot{m}_f\ (\Delta h_f - T_oS)_f + \dot{m}_a\ (\underset{T_a-537^o}{\Delta h} - T_oS)_a - m_p\ (\Delta h - T_oS)_p$$

$$\dot{m}_f\ (LHV) = .40\ (18{,}400) = \underline{7360\ B/s}$$

$$\dot{m}_f\ (\Delta h - T_oS_f) = .40[(.5 \times 23) - 518.7 \times .9] = \underline{-182\ B/s}$$

$$\Delta h_{air} = (377 - 128) = 249\ B/lb; \quad T_oS = 518.7 \times 1.7165 = 890$$

$$\dot{m}_a\ (\Delta h - T_oS) = 27.55\ (249 - 890) = \underline{-17670\ B/s}$$

$$\Delta h_p = (633 - 129.1) = 504\ B/lb$$

$$\dot{m}_p\ (\Delta h - T_oS)_p = 27.95\ (504 - 518.7 \times 1.8524) = \underline{12770\ B/s}$$

$$\dot{Ex}_D = 7360 + (-182) + (-17670) - (-12770)$$

$$\dot{Ex}_D = \underline{\underline{2278\ B/s}}$$

MIXER

$$\dot{E}x_{31} + \dot{E}x_5 = \dot{E}x_6 + \dot{E}x_D$$

$$1.45\ [(377.5 - 518.7 \times 1.7165) - (133.65 - 518.7 \times 1.6094)] +$$

$$27.95\ [(494 - 518.7 \times 1.8614) - (134.67 - 518.7 \times 1.6098)] -$$

$$29.40\ [(482.9 - 518.7 \times 1.8584) - (134.62 - 518.7 \times 1.6097)] = \dot{E}x_D$$

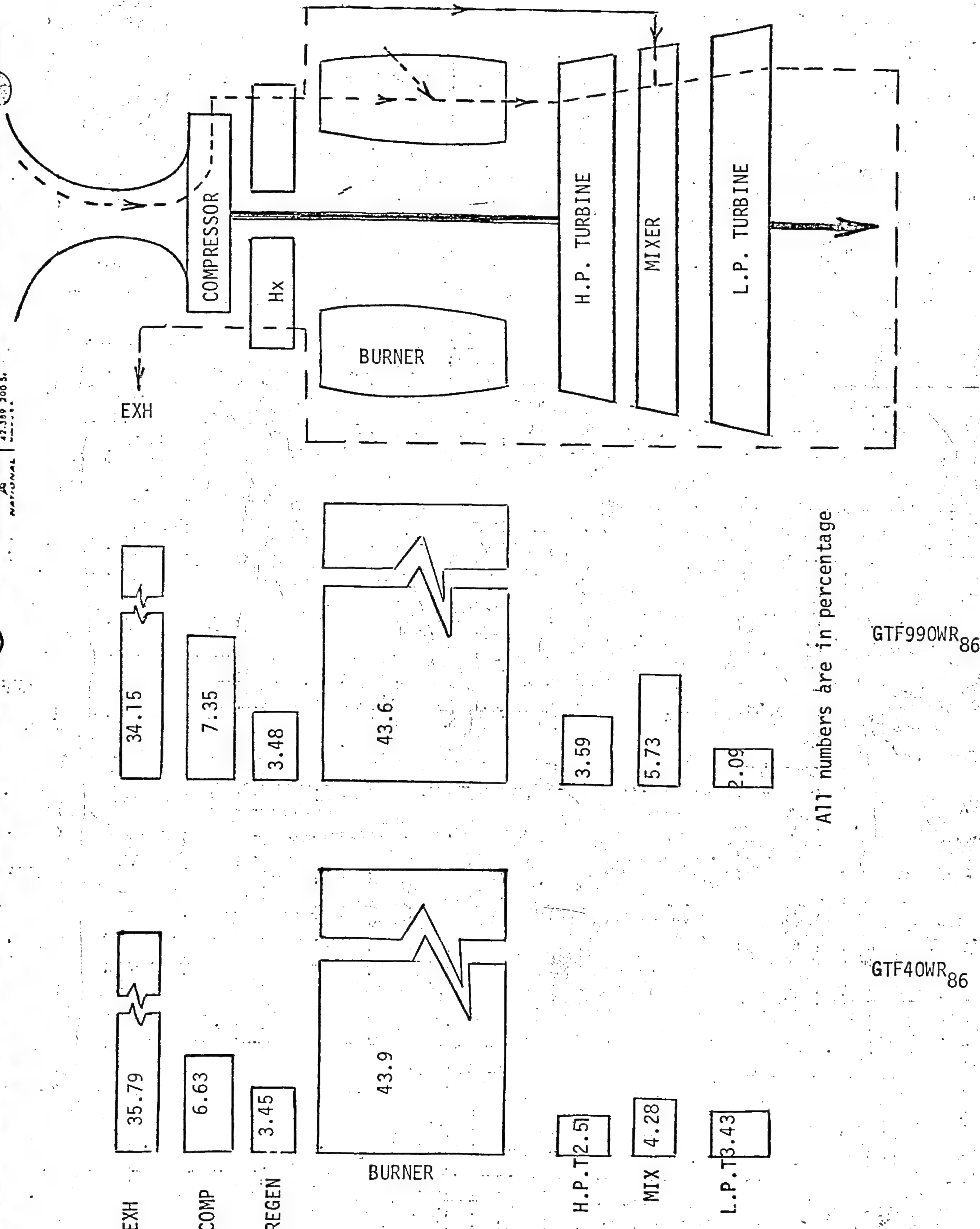
$$\dot{E}x_D = 373 + 6396 - 6447$$

$$\dot{E}x_D = \underline{\underline{222\ B/s}}$$

$$\dot{E}x_9 = 29.4\ [(296.5 - 518.7 \times 1.8000) - (134.62 - 518.7 \times 1.6097)]$$

$$\dot{E}x_9 = \underline{\underline{1857\ B/s}}$$

TOTAL		%
COMP.	344	6.63
BURNER	2278	43.91
H.P. TURB	130	2.51
MIXER	222	4.28
L.P. TURB	178	3.43
H.X.	179	3.45
EXH.	1857	35.79



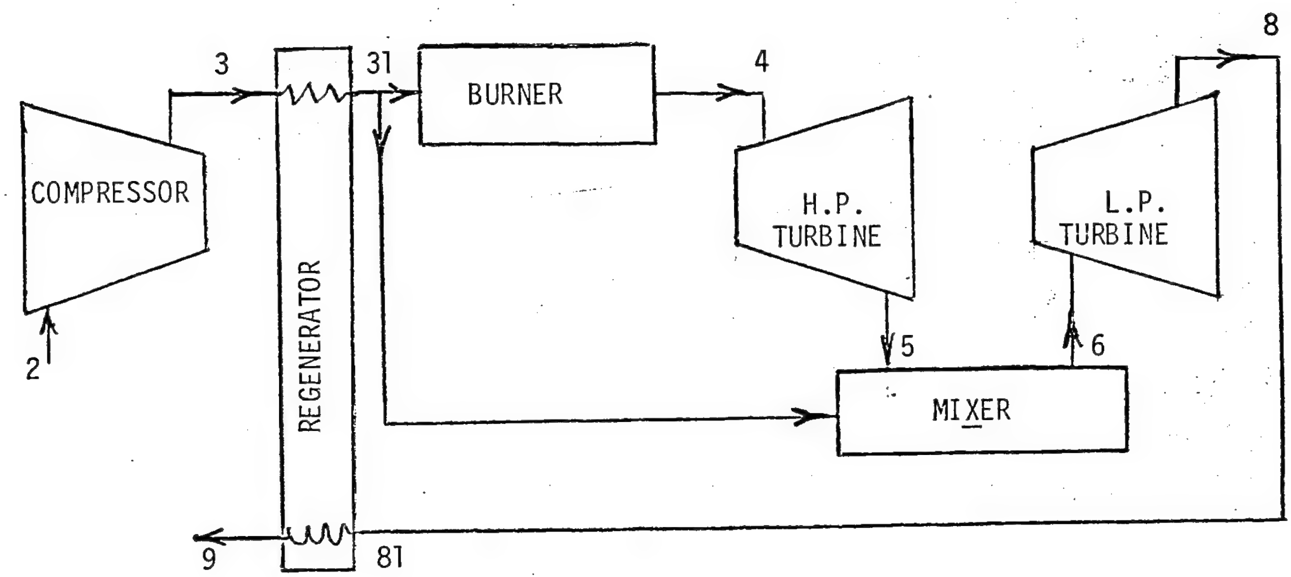
COMPARISON OF EXERGY DISSIPATION FOR $GTF990WR_{86}$ and $GTF40WR_{86}$

APPENDIX D

CALCULATIONS AND RESULTS

$GTF40WR_{96}$ (LHV = 18,400 Btu/lbm)

For this calculation we will use T_0 = 537°R, P_0 = 14.7 psia. The fuel will be one with a LHV = 18400. Schematic and state points are shown below.



The approach in this analysis is to determine the lost or dissipated exergy in each component rather than the absolute values of exergy.

STATION	TEMP R	PRESS PSI	ENTH BTU/LB	FAR	MASS FLOW LB/SEC
2	560.0	14.6	133.81		29.00
3	1107.6	119.4	267.81		27.55
31	1580.5	118.6	390.00		27.55
4	2414.7	113.9	532.14	.0136	27.93
5	1930.9	39.2	492.95	.0136	27.93
6	1892.7	37.6	481.80	.0129	29.38
8	1600.2	16.1	400.8	.0129	29.38
81	1600.2	15.8		.0129	29.38
9	1432.2	14.9	279.8	.0129	29.38

2-3 COmpressor (Q = 0)

$$\dot{W} = (267.81 - 133.81)\ 29.0 = 3886 \text{ B/s}$$

$$\dot{Ex}_2 + \dot{Ex}_W = \dot{Ex}_3 + \dot{Ex}_D$$

$$\dot{m}[(h - T_oS)_2 - (h_o - T_oS_o)] + 3886 = \dot{m}[(h - T_oS)_3 - (h_o - T_oS_o)] + \dot{Ex}_D$$

$$\phi_2 = 1.6094 \text{ B/lbm °R} = S_2$$

$$\phi_3 = 1.7758; \quad S_3 = 1.7758 - .068\ \ell n \frac{119.4}{14.7} = 1.6321$$

$$29[133.81 - 537\ (1.6094)] + 3886 - 29[267.81 - 537\ (1.6321)] = \dot{Ex}_D$$

or

$$\dot{Ex}_D = mT_o\ [S_3 - S_2] = 353.5 = \underline{\underline{354 \text{ B/s}}}$$

4-5 HP TURBINE

$$\dot{W} = 27.93\ [632.45 - 493.30] = 3886 \text{ B/s} \quad \left(\begin{matrix}\text{True only}\\ \text{if adiabatic}\end{matrix}\right)$$

$$\phi_4 = 1.9924\ ; \quad S_4 = 1.9924 - .0686\ \ell n \frac{113.9}{14.7} = 1.8519 \text{ B/lb °R}$$

$$\phi_5 = 1.9282\ ; \quad S_5 = 1.9282 - .0686\ \ell n \frac{39.2}{14.7} = 1.8609$$

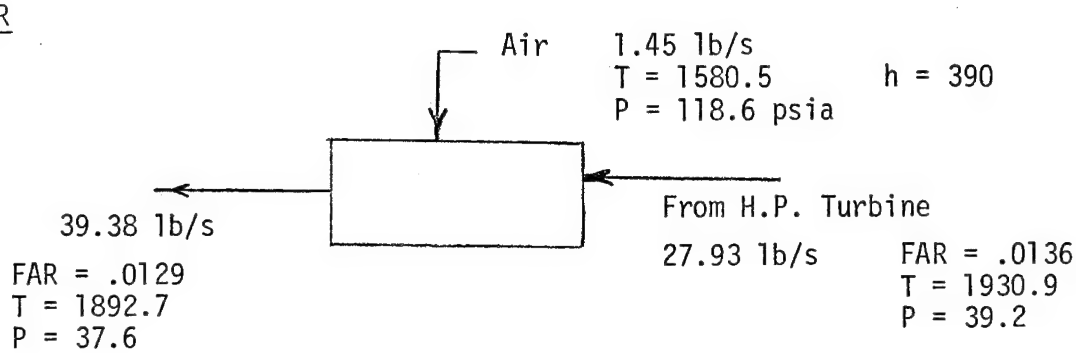
$$[(h_4 - T_oS_4) - (h_o - T_oS_o)] = [(h_5 - T_oS_5) - (h_o - T_oS_o)] + (h_4 - h_5) + ex_D$$

$$+ T_o(S_5 - S_4) = ex_D$$

$$537(1.8609 - 1.8519) = 4.83 \text{ B/lbm} = ex_D$$

$$\dot{Ex}_D = 4.83 \times 27.93 = 135 \text{ B/s}$$

MIXER



$$\dot{Ex}_A + \dot{Ex}_5 = \dot{Ex}_6 + \dot{Ex}_D$$

$$1.45[390.0 - 537 \times (1.8678 - .06855 \ell n \frac{118.6}{14.7}) - (128.2 - 537 \times 1.5993)]$$

$$+ 27.93[492.95 - 537 \times (1.9282 - .0686 \ell n \frac{39.2}{14.7}) - (129.0 - 537 \times 1.5995)]$$

$$- 29.38[481.8 - 537 \times (1.9223 - .0686 \ell n \frac{37.6}{14.7}) - (129.0 - 537 \times 1.5996)]$$

$$= \dot{Ex}_D$$

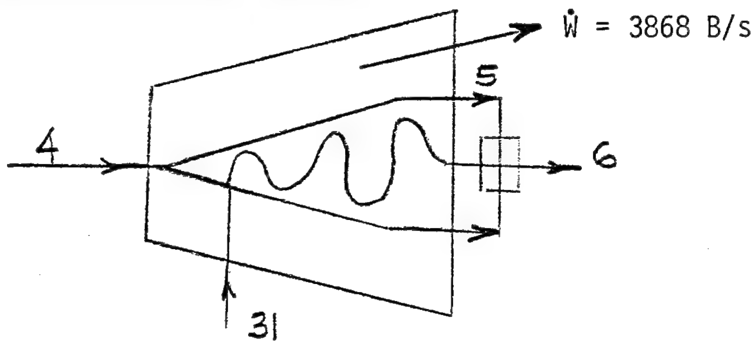
$$\dot{Ex}_D = 282 + 6244 - 6290 = \underline{\underline{236 \text{ B/s}}}$$

$$\text{H.P. Turb \& mix } \dot{Ex}_D = 135 + 236 = \underline{\underline{371 \text{ B/s}}}$$

COMPARE WITH NEXT PAGE

(alternate approach)

COMBINED TURBINE & MIXER



ϕ_{31} = 1.8678 $\quad S_{31} = 1.8678 - .0686 \ln \frac{118.6}{14.7} = 1.7246$ B/lbm °R

ϕ_6 = 1.9223 $\quad S_6 = 1.9223 - .0686 \ln \frac{37.6}{14.7} = 1.8579$

Check energy balance

$$(632.45)\ 27.93 + (390.41)(1.45) = 3886 + (482.17)(29.38)$$

$$18230 = 18052 \quad \simeq 1\% \text{ off}$$

$$\dot{m}_4[(h_4 - T_oS_4) - (h_o - T_oS_o)] + \dot{m}_{31}[(h_{31} - T_oS_{31}) - (h_o - T_oS_o)]$$

$$= \dot{W} + \dot{m}_6[(h_6 - T_oS_6) - (h_o - T_oS_o)] + \dot{Ex}_D$$

Note: h_{fg} on both sides will cancel

$$27.93[(632.45 - 537 \times 1.8519) - (129 - 537 \times 1.5996)] +$$

$$1.45[(390.41 - 537 \times 1.7246) - (128.2 - 537 \times 1.5993)] - 3886$$

$$- 29.38[(482.17 - 537 \times 1.8579) - (129.00 - 537 \times 1.5997)] = \dot{Ex}_D$$

$\underline{\underline{\dot{Ex}_D = 373 \text{ B/s}}}$

BURNER

Use $S_{fuel} \approx 0.9$ B/lbm °R and let $T_{fuel} = T_{537} = T_o$

$$\dot{E}x_D = \dot{m}_f(LHV) + \dot{m}_f(\Delta h_f - T_oS_f) + \dot{m}_{air}(\underset{T_o-537}{\Delta h} - T_oS)_{air}$$

$$- \dot{m}_p(\underset{T_p-537}{\Delta h_p} - T_oS)_p$$

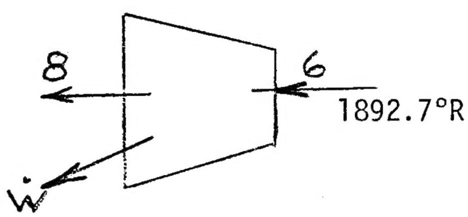
$$= (.38)(18400) + .38(0 - 537 \times .9) + 27.55[(390.0 - 128.2) - 537 \times 1.7246]$$

$$- 27.93[(632.1 - 129.0) - 537 \times 1.8519]$$

$$\dot{E}x_D = 6992 - 184 - 18{,}302 + 13724$$

$$\underline{\underline{\dot{E}x_D = 2230 \text{ B/s}}}$$

L.P. TURBINE



$h_6 = 481.8$ $S_6 = 1.8579$

$h_8 = 400.8$ $S_8 = 1.8758 - .0686 \ln \frac{16.1}{14.7}$

$S_8 = 1.8696$

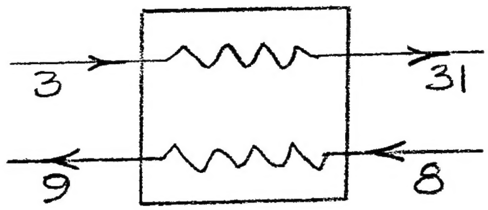
$$\dot{W} = 29.38(481.8 - 400.8) = 2379.8 \text{ B/s}$$

$$\dot{E}x_6 = \dot{E}x_8 + \dot{E}x_W + \dot{E}x_D$$

$$29.38[481.8 - 537 \times 1.8579 - (h_o - T_oS_o)] - 29.38[(400.8 - 537 \times 1.8696) - (h_o - T_oS_o)]$$

$$- \dot{W} = \dot{E}x_D \qquad \therefore \dot{E}x_D = 537(1.8696 - 1.8579)\ 29.38 = \underline{\underline{185 \text{ B/s}}}$$

HEAT EXCHANGER



$$\dot{Ex}_3 + \dot{Ex}_8 = \dot{Ex}_{31} + \dot{Ex}_9 + \dot{Ex}_D$$

$$\dot{m}_3[(h_3 - T_0S_3) - (h_0 - T_0S_0)_{3-31}] + \dot{m}_8[(h_8 - T_0S_8) - (h_0 - T_0S_0)_{8-9}] =$$

$$\dot{m}_3[(h_{31} - T_0S_{31}) - (h_0 - T_0S_0)_{3-31}] + \dot{m}_8[(h_9 - T_0S_9) - (h_0 - T_0S_0)_{8-9}] + \dot{Ex}_D$$

$$29[(267.81 - 537 \times 1.6321)] + 29.38\ [(400.8 - 537 \times 1.8696)] =$$

$$29[390 - 537 \times 1.7246] + 29.38[279.8 - 537(1.7869 - .0686\ \ell n\ \frac{14.9}{14.7}) + \dot{Ex}_D$$

$$-17.650 - 17721 + 15535 + 19957 = \dot{Ex}_D$$

$$\underline{\underline{\dot{Ex}_D = 121\ \text{B/s}}}$$

The regenerator eff $= \dfrac{h_{31} - h_3}{h_{31} - h_3}$ where h_{31} = enthalpy of air at T_8

$$\text{eff} = \frac{390.41 - 267.81}{395.23 - 267.81} = .96$$

$$\dot{Ex}_9 = [(h_9 - T_0S_9) - (h_0 - T_0S_0)]\dot{m}$$

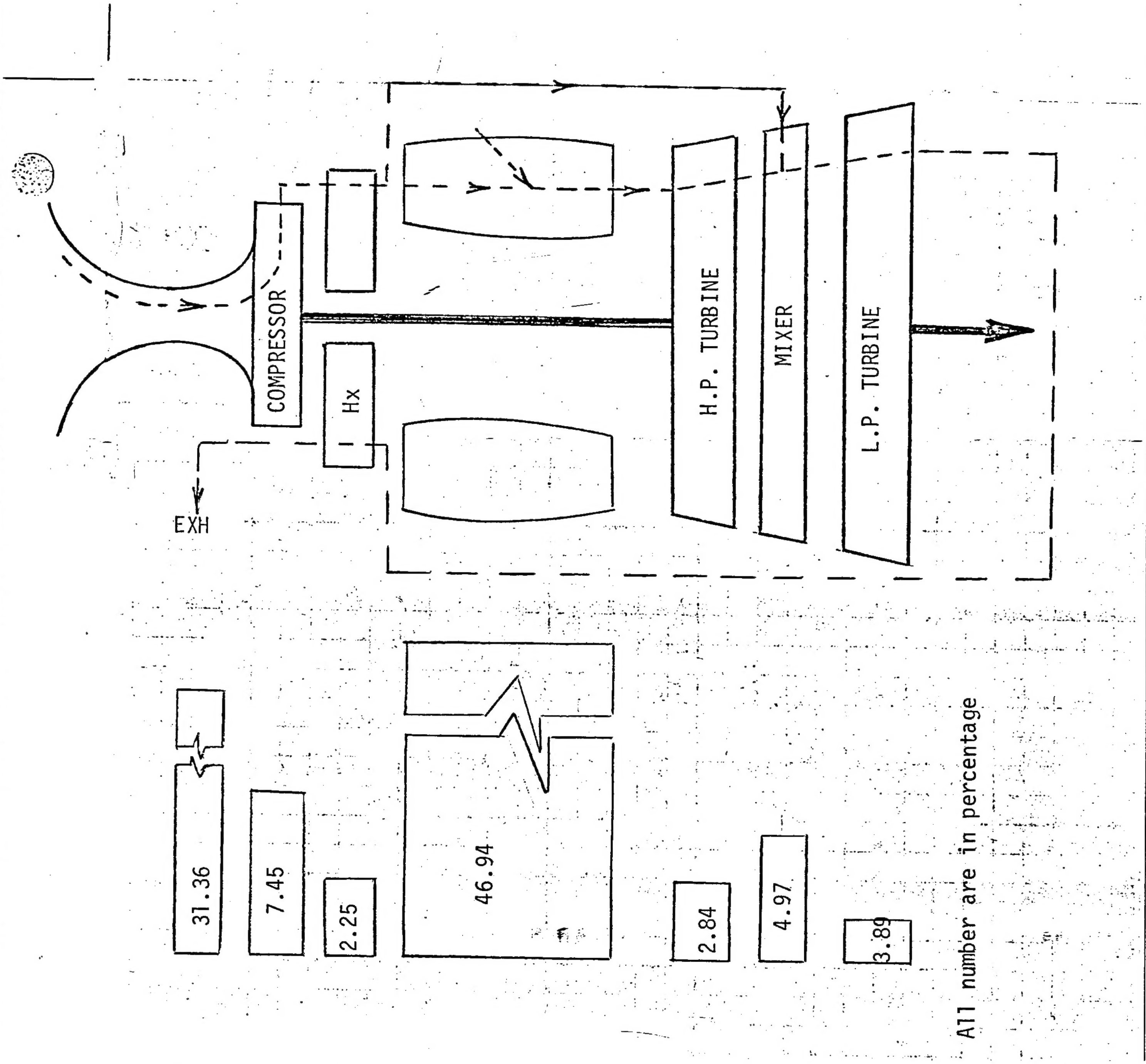
$$= 29.38[[279.8 - 537 \times (1.7869 - .0686\ \ell n\ \frac{14.9}{14.7})]$$

$$- [129 - 537 \times 1.5996]]$$

$$\dot{Ex}_9 = 29.38\{[279.8 - 537 \times 1.7860] - [129 - 859]\}$$

$$\underline{\underline{\dot{Ex}_9 = 1490\ \text{B/s}}}$$

DISSIPATED EXERGY		PERCENT
COMPRESSOR	354	7.45
H.P. TURBINE	135	2.84
MIXER	236	4.97
BURNER	2230	46.94
L.P. TURBINE	185	3.89
REGENERATOR	121	2.55
EXHAUST	1490	31.36
	4751	100.00



EXERGY DISSIPATION FOR GTF40WR96